Human Exploration and Operations Mission Directorate

Budget Status for
NASA Advisory Council
Human Exploration and Operations Committee

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Associate Administrator

March 26, 2018

Human Exploration and Operations

Agenda

- Exploration Campaign
- FY 2019 Strategy/Budget Overview
- Programs
  - Advanced Exploration Systems
    - Lunar Orbital Platform - Gateway
    - Advanced Cislunar and Surface Capabilities
    - Exploration Advanced Systems
  - Exploration Systems Development
    - Orion
    - Space Launch System
    - Exploration Ground Systems
  - International Space Station
  - Commercial LEO Development
  - Space Transportation
    - Crew and Cargo Program
    - Commercial Crew Program
  - Space and Flight Support
    - Space Communications and Navigation
    - Rocket Propulsion Test
    - Launch Services Program
    - Human Space Flight Operations

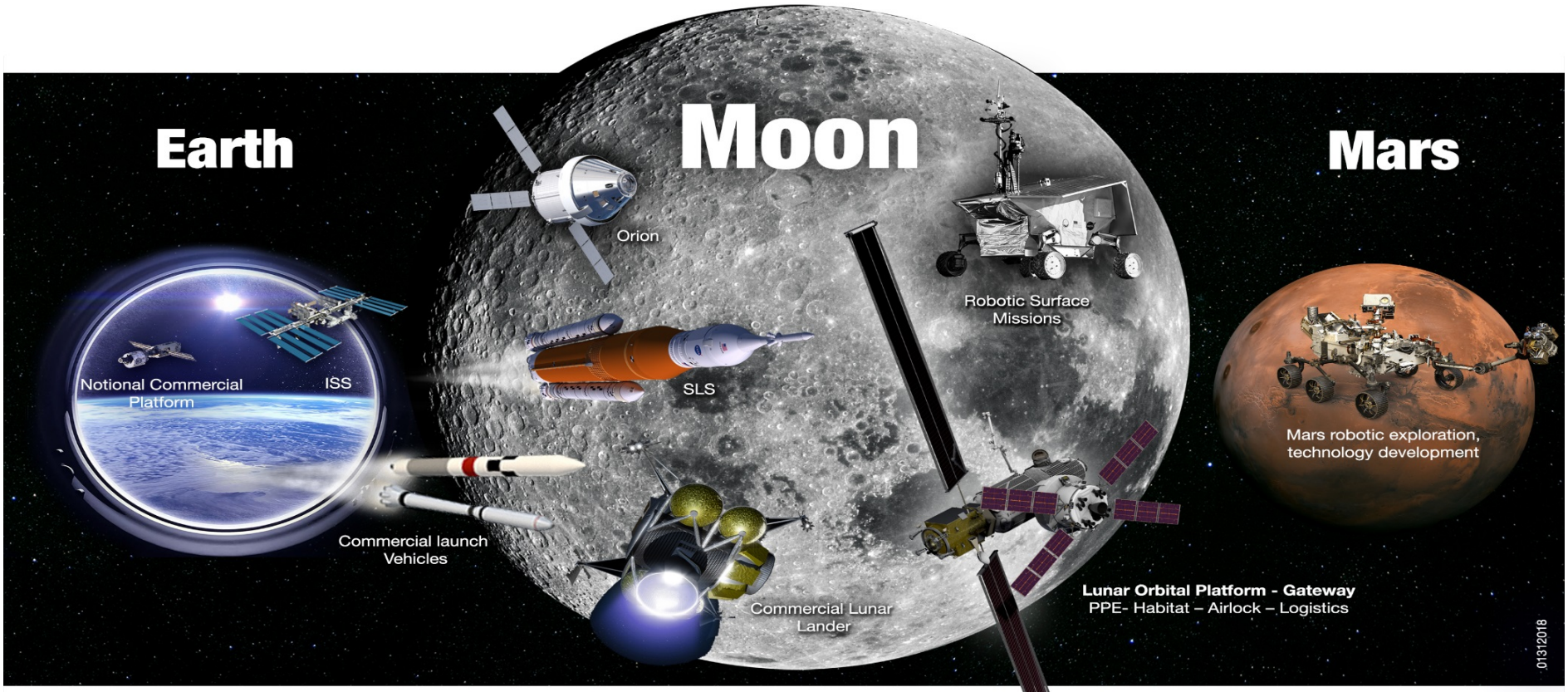
Space Policy Directive-1

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.

Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

Human Exploration and Operations

Exploration Campaign



In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions

Human Exploration and Operations

Exploration Campaign

- Prioritize human exploration and related activities
- Expand Exploration by
  - Providing funding to start transition of low Earth orbit human space flight operations to commercial partners
  - Pursuing a cislunar strategy that establishes U.S. preeminence to, around, and on the Moon, including commercial partnerships and innovative approaches, to achieve human and science exploration goals

	Fiscal Year						
	Enacted	CR	Request	Notional			
Budget Authority ($ in millions)	2017	2018	2019	2020	2021	2022	2023
Deep Space Exploration Systems	$4,184.0	$4,222.6	$4,558.8	$4,859.1	$4,764.5	$4,752.5	$4,769.8
Exploration Research and Technology	$826.5	$820.8	$1,002.7	$912.7	$912.7	$912.7	$912.7
LEO and Spaceflight Operations	$4,942.5	$4,850.1	$4,624.6	$4,273.7	$4,393.3	$4,430.3	$4,438.0
Exploration Campaign CoF	$45.5	$22.4	$44.8	$0.0	$0.0	$0.0	$0.0
Elements of Science	$39.0	$36.0	$268.0	$268.0	$268.0	$268.0	$268.0
EXPLORATION CAMPAIGN TOTAL	$10,037.5	$9,951.9	$10,498.9	$10,313.5	$10,338.5	$10,363.5	$10,388.5

Human Exploration and Operations

Exploration Campaign (continued)

- To support the Nation's new Space Policy, the initiative is funded at $10.5 billion in the FY 2019 President's Budget (a $547 million increase in FY 2019 when compared to the current FY 2018 CR). In total, the Budget proposes $52 billion from 2019-2023 for the exploration strategy, and is centered on
  - Finalizing the development of the Space Launch System rocket and Orion crew capsule for EM-1 flight in FY 2020 and then to send astronauts to the area around the Moon beginning in 2023, and roughly annually thereafter
  - A new initiative for a Lunar Orbital Platform – Gateway to serve as a destination in the lunar vicinity by 2025
  - A new joint SMD and HEOMD initiative to develop small and mid-size lunar robotic lander capabilities through a combination of commercial and in-house efforts, beginning with commercial lunar landings as early as 2019
  - A new Commercial Low Earth Orbit (LEO) program to incentivize new commercial capabilities in LEO
  - A new Exploration Research and Technology account that merges elements of prior technology programs and focuses them on meeting exploration needs
    - Human Research Program (HRP) will continue research on effect of Spaceflight to the human body, will support development of Deep Space Exploration habitat concepts to ensure crew health and performance risks are adequately addressed; NASA is currently working on a reorganization that will take effect later this fiscal year. Until then, HEOMD and STMD will continue to manage their respective programs

Human Exploration and Operations

Exploration Campaign (continued)

- In addition to these areas, NASA will continue pursuing other human spaceflight programs, most notably the International Space Station and the advancement of commercial crew and cargo transportation services and capabilities
- At the end of the five years proposed in the Budget, NASA plans to have
  - Achieved uncrewed and crewed test launch of the SLS and Orion system,
  - Launched two of the initial elements of the Lunar Orbital Platform - Gateway (to be completed with two additional launches by 2025)
  - Supported numerous commercial lunar robotic landings and developed commercial lunar landing capabilities to support future NASA mission needs
  - Developed key technologies needed to make exploration more capable and cost-effective, and
  - Established a pathway to enable a seamless transition from direct NASA financial support to the ISS in 2025

Human Exploration and Operations

Agency Restructure

- NASA proposes to restructure and align HEOMD and STMD to enhance our ability to accelerate human exploration beyond low Earth orbit. Two options are currently under review
  1. Create two new exploration-focused mission directorates, eliminating the current HEOMD and STMD structure
     - Exploration Operations Mission Directorate, which will focus on ISS, Commercial LEO operations, and cross cutting Space Flight Support areas required to support exploration
     - Exploration Systems and Technology Mission Directorate, which will focus on deep space mission elements and technology development needs for sustainable human exploration in deep space
  2. Create a single exploration-focused mission directorate, consolidating all the exploration-focused content in the current HEOMD and STMD
- NASA will assess these two options (and any hybrid options that may arise), and prepare for implementation by the start of FY 2019 budget year

Human Exploration and Operations

Strategic Principles for Sustainable Exploration

- FISCAL REALISM: Implementable *with the buying power of current budgets*
- COMMERCIAL PARTNERSHIPS: Leveraging the unique capabilities of NASA and the private sector, use partnerships to develop safe, reliable, and cost-effective space systems, while simultaneously developing a commercial LEO space economy
- SCIENTIFIC EXPLORATION*: Exploration enables science and science enables exploration;* leveraging scientific expertise for human exploration of the solar system
- TECHNOLOGY PULL AND PUSH: Application of high TRL technologies for near term missions, while focusing sustained investments on *technologies and capabilities* to address the challenges of future missions
- GRADUAL BUILD UP OF CAPABILITY: *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time
- ARCHITECTURE OPENNESS AND RESILIENCE : Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions
- GLOBAL COLLABORATION AND LEADERSHIP: Substantial *new international and commercial partnerships,* leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and
- CONTINUITY OF HUMAN SPACEFLIGHT*: Uninterrupted expansion of human presence into the solar system* by establishing a regular cadence of crewed missions to cislunar space during ISS lifetime

Human Exploration and Operations

FY 2019 Budget Strategy/Overview

- FY 2019 budget submit provides approximately $9.2B for HEO (not including ERT and SMD Lunar) to continue pursuit of Administration and NASA Exploration goals, consistent with National Space Council's Space Policy and NASA Transition Authorization Act of 2017
- HEO's submit supports NASA's Exploration Campaign and enables expansion of human presence into the solar system, with robust capabilities that ensure flexibility in destination, affordability and sustainability
  - Develop next generation transportation capabilities for human exploration in cislunar space (Orion crew capsule, SLS rocket, and EGS)
    - Enabling exploration in cislunar space, the first uncrewed test flight of the SLS/Orion system will occur in FY 2020, leading to crewed mission in NET September 2022 to NLT April 2023
  - Establish Lunar Orbital Platform-Gateway (LOP-G) as a platform to mature necessary short- and long-duration exploration capabilities, as an enabler to lunar surface science and exploration, and as a staging point for deep space exploration
    - Includes four main capabilities by 2025: Power and Propulsion Element (PPE), habitation, airlock capabilities to enable Extra-Vehicular Activities (EVA) and science operations, and required logistics capabilities
    - Advances Solar Electric Propulsion through PPE in 2022, the first component, which will provide deep space power and propulsion as well as communication capability through a public-private partnership that is directly applicable to a wide range of NASA, commercial, robotic, and human spaceflight missions

Human Exploration and Operations

FY 2019 Budget Strategy/Overview (continued)

- Enables potential opportunities for international collaboration leveraging current ISS and other partnerships

- Initiate planning of Advanced Cislunar and Surface Capabilities, that will with other Exploration Campaign activities once again establish U.S. preeminence to, around, and on the Moon
  - Working in parallel with SMD lunar exploration, HEO is planning to develop a series of progressively more capable lunar missions to the surface of the moon which will serve as a foundational training ground to prepare for utilization of the Moon and later missions to Mars
  - NASA will use innovative acquisition approaches to enable U.S. commercial capabilities to be leveraged toward human exploration of the lunar surface, and will also partner with international partners as appropriate in this endeavor
- Develop capabilities required for future deep space missions
  - Research human health and performance so crew can travel and live safely in deep space (funded in Exploration and Research and Technology account)
  - Partner with industry to prototype habitats, life support systems, and other habitation technologies ready to feed forward and conduct integrated ground testing; continues ISS-based testing to reduce risk for deep space missions
- Increase efforts to facilitate the development of a commercial space economy in LEO
  - Stimulate the development and maturation of the commercial LEO space market, platforms, and operational capabilities to enable private industry to assume roles that have been traditionally government-only

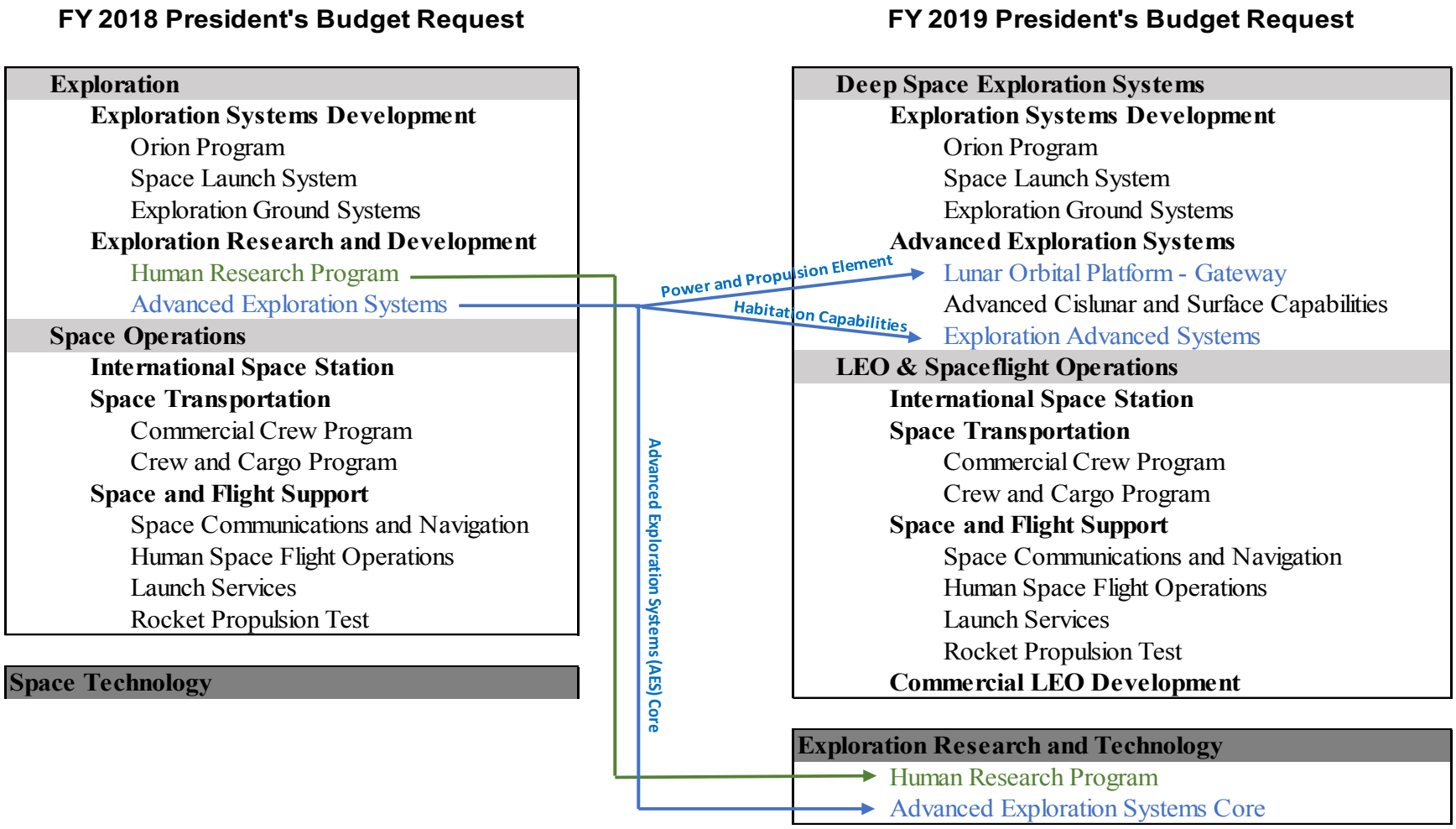
Human Exploration and Operations

FY 2019 Budget Strategy/Overview (continued)

- Advance commercial crew space transportation to LEO with two commercial partners strengthening U.S. global leadership
  - Partnering with commercial space industry for human access to ISS and other LEO destinations bolsters American leadership, reduces our current reliance on foreign providers and helps stimulate the American aerospace industry
- Purchase reliable cargo resupply services from U.S. private sector companies
  - Made improvements to Commercial Resupply Service (CRS)-2 contract by leveraging lessons learned from CRS-1
- Provide critical communication, navigation, launch services, rocket propulsion testing, and other services to NASA, and external customers, such as Next Generation Earth Relay (considering commercial industries where feasible) required for future missions
- Invest in commercial capabilities and approaches necessary to ensure a seamless transition for ending direct federal financial support for the ISS in 2025, as NASA leads a coalition of international and commercial partners in LEO, to the Moon, and then Mars and beyond
  - While direct financial support for the ISS ends in 2025, NASA would intend to continue to financially support research and other activity in low-earth orbit post-2025

Human Exploration and Operations

Budget Structure Crosswalk



- The FY 2019 Budget includes a new account structure for human space exploration and technology programs to improve alignment of funding with NASA's new strategic space exploration objectives
- This crosswalk only addresses structure changes to the current Exploration account

Human Exploration and Operations

Program Financial Plan

Budget Authority ($ in millions)	Actual 2017	CR *2018	Request 2019	Notional 2020	2021	2022	2023
Human Exploration and Operations	**9,126.5**	**9,072.7**	**9,183.4**	**9,132.8**	**9,157.8**	**9,182.8**	**9,207.8**
Deep Space Exploration Systems	**4,184.0**	**4,222.6**	**4,558.8**	**4,859.1**	**4,764.5**	**4,752.5**	**4,769.8**
Exploration Systems Development	**3,929.0**	**3,902.3**	**3,669.8**	**3,790.5**	**3,820.2**	**3,707.5**	**3,845.6**
Orion Program	1,330.0	1,340.8	1,163.5	1,137.7	1,134.2	1,117.8	1,117.8
Space Launch System	2,127.1	2,135.4	2,078.1	2,062.9	2,165.1	2,131.0	2,276.0
Exploration Ground Systems	471.9	426.1	428.2	589.9	520.8	458.7	451.9
****Advanced Exploration Systems**	**255.0**	**-**	**889.0**	**1,068.6**	**944.4**	**1,045.0**	**924.1**
Adv Cislunar and Surface Capabilities	-	-	116.5	146.0	163.7	300.0	320.3
***Exploration Advanced Systems	255.0	-	268.2	260.7	240.6	186.1	144.7
Lunar Orbital Platform - Gateway	-	-	504.2	662.0	540.1	558.9	459.1
Power and Propulsion Element	-	-	*327.9*	*210.9*	*108.4*	*43.4*	-
Habitation	-	-	*176.3*	*191.5*	*110.7*	*98.0*	*51.0*
Airlock	-	-	-	*89.1*	*124.7*	*221.6*	*267.0*
Logistics	-	-	-	*170.5*	*196.3*	*195.9*	*141.1*
LEO and Spaceflight Operations	**4,942.5**	**4,850.1**	**4,624.6**	**4,273.7**	**4,393.3**	**4,430.3**	**4,438.0**
International Space Station	**1,450.9**	**-**	**1,462.2**	**1,453.2**	**1,471.2**	**1,466.2**	**1,451.2**
Space Transportation	**2,589.0**	**-**	**2,108.7**	**1,829.1**	**1,858.9**	**1,829.2**	**1,807.3**
Commercial Crew Program	1,184.8	-	173.1	35.8	36.3	36.3	36.3
Crew and Cargo Program	1,404.2	-	1,935.6	1,793.2	1,822.6	1,792.8	1,771.0
Space and Flight Support	**902.6**	**-**	**903.7**	**841.4**	**888.2**	**934.9**	**954.6**
21st Century Space Launch Complex	20.0	-	-	-	-	-	-
Space Communications and Navigation	630.1	-	634.1	568.8	615.6	652.9	670.6
Human Space Flight Operations	123.1	-	135.4	136.4	136.4	145.9	147.8
Launch Services	85.7	-	86.6	88.6	88.6	88.6	88.6
Rocket Propulsion Test	43.7	-	47.6	47.6	47.6	47.6	47.6
Commercial LEO Development	**-**	**-**	**150.0**	**150.0**	**175.0**	**200.0**	**225.0**
Construction and Environment Compliance Restoration	**45.5**	**37.0**	**44.8**	**-**	**-**	**-**	**-**
Deep Space Exploration Systems	**8.8**	**20.4**	**25.9**	**-**	**-**	**-**	**-**
Space Launch System	5.8	-	-	-	-	-	-
Exploration Ground Systems	3.0	-	-	-	-	-	-
LEO and Spaceflight Operations	**36.7**	**16.6**	**18.9**	**-**	**-**	**-**	**-**
Rocket Propulsion Test	3.9	-	-	-	-	-	-
21st Century Space Launch Complex	3.4	-	-	-	-	-	-
Space Communications and Navigation	26.5	-	-	-	-	-	-
Launch Services	2.9	-	-	-	-	-	-

**FY 2018 reflects FY 2017 Enacted with 0.67% rescission*

*** HRP was transferred to Exploration Research and Technology account but will continue to be executed in FY 2018 under the Exploration account and managed by HEO*

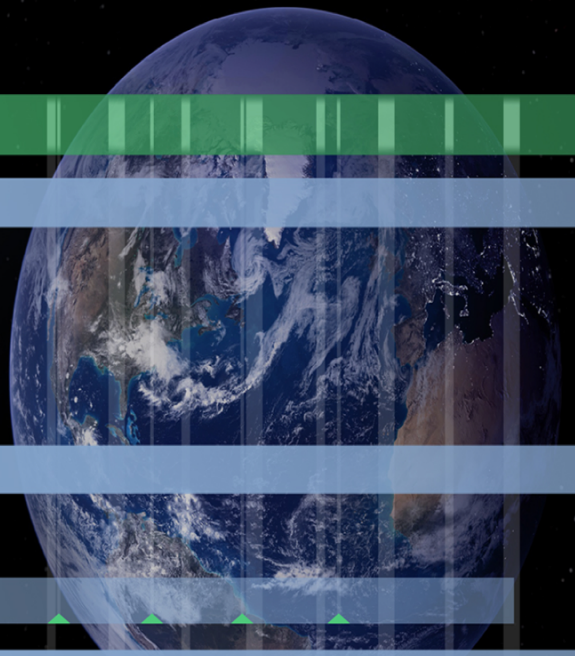
**** In FY 2017 and FY 2018 EAS includes AES content that was previously executed under ERD theme in Exploration account*

Totals may not add due to rounding

Advanced Exploration Systems

Lunar Orbital Platform - Gateway
Advanced Cislunar and Surface Capabilities
Exploration Advanced Systems

NASA Exploration Campaign



NOTIONAL LAUNCHES

EARLY SCIENCE & TECHNOLOGY INITIATIVE

- **SMD**–Pristine Apollo Sample, Virtual Institute
- **HEO/SMD**–Lunar CubeSats
- **SMD**/HEO–Science & Technology Payloads

SMALL COMMERCIAL LANDER INITIATIVE

- **HEO**–Lunar Catalyst & Tipping Point
- **SMD**/HEO–Small Commercial Landers/Payloads

MID TO LARGE LANDER INITIATIVE TOWARD HUMAN-RATED LANDER

- **HEO**/SMD–Mid-sized Landers (~500kg–1000kg)
- **HEO**/SMD–Human Descent Module Lander (5-6000kg)
- **SMD**/HEO–Payloads & Technology/Mobility & Sample Return
- **SMD**–Mars Robotics

LUNAR ORBITAL PLATFORM—GATEWAY

- **HEO**–Orion/SLS (Habitation Elements/Systems)
- **HEO**/SMD–Gateway Elements (PPE, Commercial Logistics)/Crew Support of Lunar Missions
- **HEO**/SMD–Lunar Sample Return Support

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

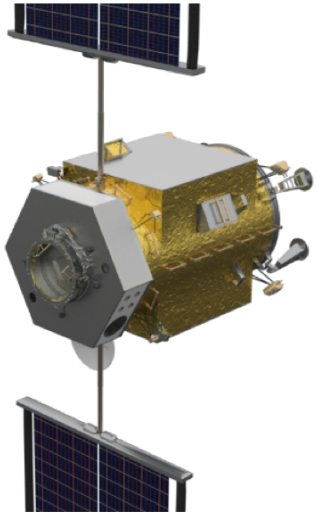
Timelines are tentative and will be developed further in FY 2019

MARCH 2018

Human Exploration and Operations

Lunar Orbital Platform-Gateway: Overview

- Will be assembled in orbit around the Moon by 2025 where it can also be used as a staging point for missions to the lunar surface and to destinations in deep space
- Provides a flexible human exploration architecture and will include four main capabilities
  - Power and Propulsion Element (PPE)
    - First LOP-G capability targeted for launch readiness in 2022
    - Spaceflight demonstration of advanced solar electric propulsion spacecraft for join industry and government objectives
    - Developing through a public private partnership
    - Will provide transportation and controls for lunar orbital operations, power to future lunar orbiting elements and communications



Notional graphic of PPE
Power:40kW EOL;
Propulsion: EP main and chemical RCS

Human Exploration and Operations

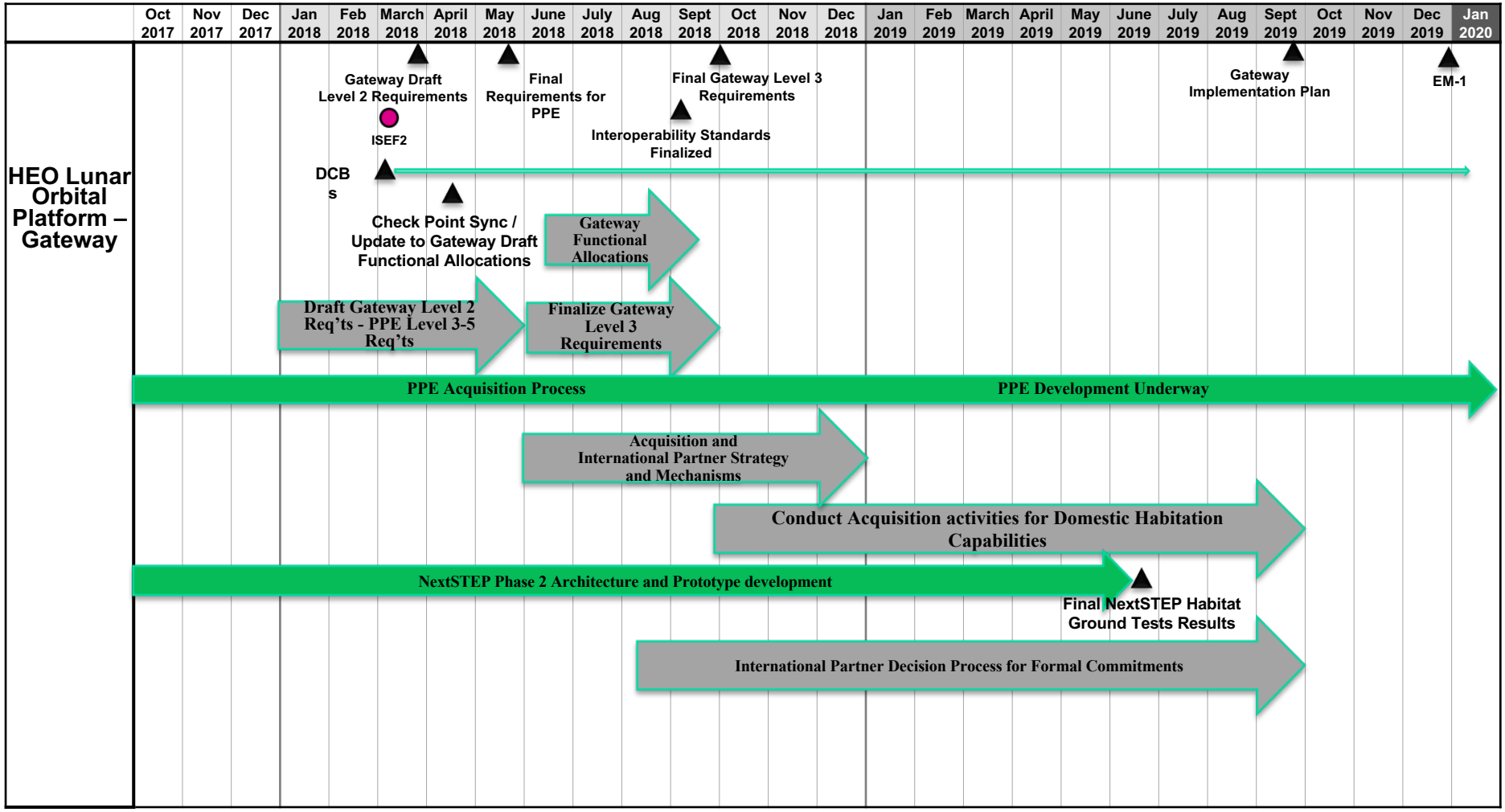
Lunar Orbital Platform-Gateway: Overview (continued)

- Small Habitation
  - Provides habitable volume and short-duration life support functions for crew in cislunar space
  - Provides docking ports for attachment to PPE, other LOP-G elements and visiting vehicles
  - Offers attach points for external robotics, external payloads or rendezvous sensors
  - Provides accommodations for crew exercise, science/utilization and stowage
- Airlock
  - Provides capability to enable astronaut EVAs as well as potential to accommodate docking of additional elements, observation ports, or a science utilization airlock
- Logistics
  - Delivers cargo to enable extended crew mission durations, science utilization, exploration technology demonstrations, potential commercial utilization, and other supplies

- NASA plans to launch the PPE in 2022 on a commercial launch vehicle, while the other three would be launched on SLS, beginning in 2023

Human Exploration and Operations

Lunar Orbital Platform-Gateway: Top level schedule



Human Exploration and Operations

Lunar Orbital Platform-Gateway: FY 2018 and FY 2019 Plans

- Define system requirements, develop design and interoperability standards, establish program and system-level control boards, develop strategy and execution mechanisms
- PPE will perform requirements studies, acquisition planning, and partnership approaches in coordination with STMD
  - Award contract(s) for PPE spacecraft development
  - Made final selections for further PPE industry studies from NextSTEP BAA Appendix C submittals
  - Conduct reviews for requirements and preliminary design, and procurement of long lead items
  - Establish acquisition strategy for launch vehicle
- Develop long duration deep space architecture designs (including standards, common interfaces, and testing approaches) using NextSTEP Phase 2 ground prototype test results
- Evaluate alternative habitation prototypes implementation strategies focused on international capabilities and contributions
- Solidify acquisition and partnership plans to begin formulation of remaining functions/elements of LOP-G
- Initiate acquisition and partnering efforts for habitation functions for LOP-G in FY 2019

Human Exploration and Operations

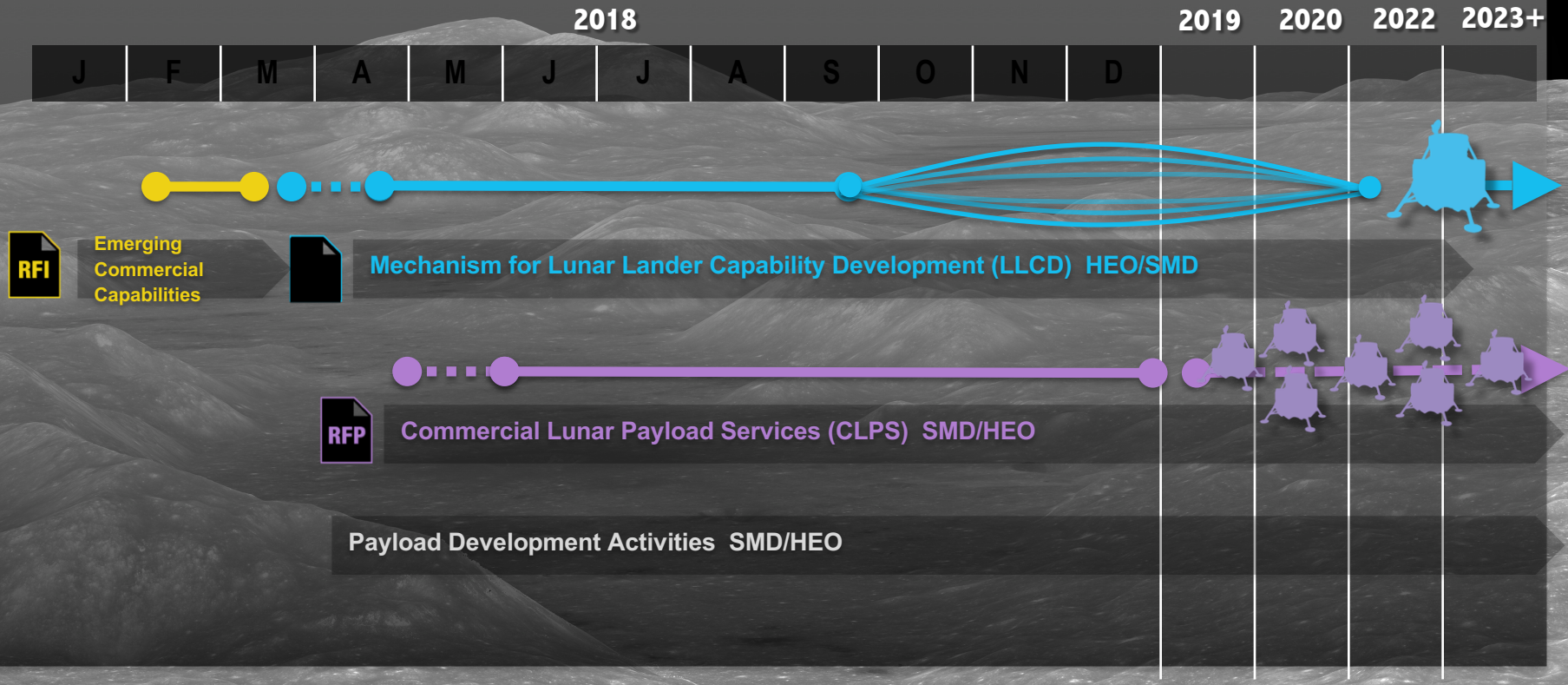
Advanced Cislunar and Surface Capabilities: Overview

- Use innovative approaches for Advanced Cislunar and Surface Capabilities (ACSC) to combine lunar robotics, a cislunar presence, and lunar landing capabilities
  - Involve commercial and international participation to enhance U.S. leadership and establish U.S. preeminence to, around, and on the Moon
  - Use Mid to large class lander activity to allow NASA workforce to understand and develop human rated lander requirements
- Partner with SMD's new Lunar Discovery and Exploration Program to build and launch instruments that serve lunar science, long-term exploration and utilization needs
- Develop commercial lunar landing capabilities to support future NASA mission needs, reduce risk, and stimulate commercial investments and activities in cislunar space
  - Validate commercial capabilities and explore business cases for lunar payload delivery by purchasing instrument delivery services and technology demonstrations as soon commercially available
  - Partner with industry to evolve capabilities for mid-size (500-1000 kg of payload) landers, to be demonstrated in 2022 and 2024, and could deliver payloads such as lunar resource prospecting, ascent stages for sample return missions, and infrastructure to support future missions
  - Advance capabilities to continue support for developing a human class lander (5000-6000 kg of payload) to enable progress towards landing humans on the Moon

Human Exploration and Operations

Advanced Cislunar and Surface Capabilities:
Near-term Lunar Lander and Payload Activities

NASA will once again establish U.S. preeminence to, around, and on the Moon. In addition to establishing the Lunar Orbital Platform – Gateway, NASA is planning to develop a series of progressively greater robotic missions to the surface of the moon, with the goal of evolving toward human lander capabilities. The activities highlighted below build on the progress of the **Lunar CATALYST** partnerships and foster opportunities for increasingly greater payload capabilities to the lunar surface.



Human Exploration and Operations

Advanced Cislunar and Surface Capabilities: FY 2018 and FY 2019 Plans

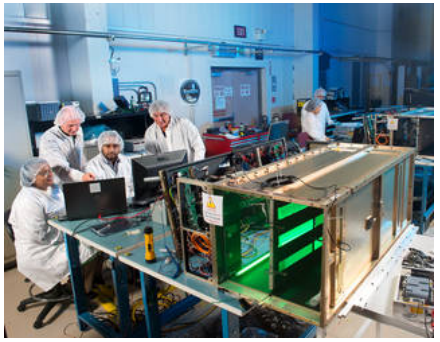
- Issue joint Request For Information (RFI) with SMD in February 2018 regarding emerging commercial capabilities, short and long term mission plans, and commercial sector opportunities to enable regular access to the lunar surface, and innovative public-private partnership acquisition approaches
- Solicit a March 2018 NextSTEP announcement for lander risk reduction activities and concepts that start with an initial capability of landing a minimum of 500kg payload(s) on the lunar surface
- Initiate discussions with international partners to establish interest in LOP-G and ACSC
- Evaluate Lunar CATALYST partnerships efforts that can be directly linked to ACSC
  - Encourage the development of robotic lunar landers that can be integrated with U.S. commercial launch capabilities to the lunar surface
- Begin initial planning of a series of robotic demonstration missions expected to start at the 500kg payload class in the early half of the 2020s with the expectation of larger (5000-6000kg) class in the second half of the 2020s

Astrobotic Technology's Griffin lander concept

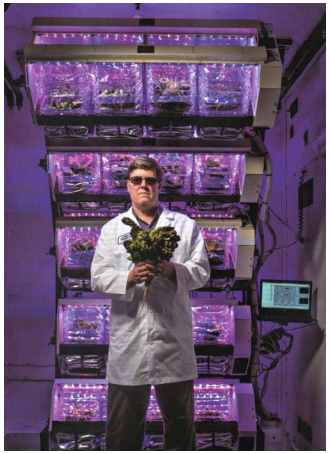
Human Exploration and Operations

Exploration Advanced Systems: Overview

- Reduce operational risk and lifecycle costs for LOP-G and longer duration missions such as essential Mars transit and planetary surface missions
  - Develop prototype deep space habitats for ground-based testing, while simultaneously stimulating commercial habitat development in low Earth orbit
- Implement phased approach to advance habitation systems development, demonstration and operations on ISS, followed by incremental deployment leading to an integrated habitation capability in cislunar space
- Provide innovative approaches for rapid and affordable development and demonstrate systems needed for future human exploration



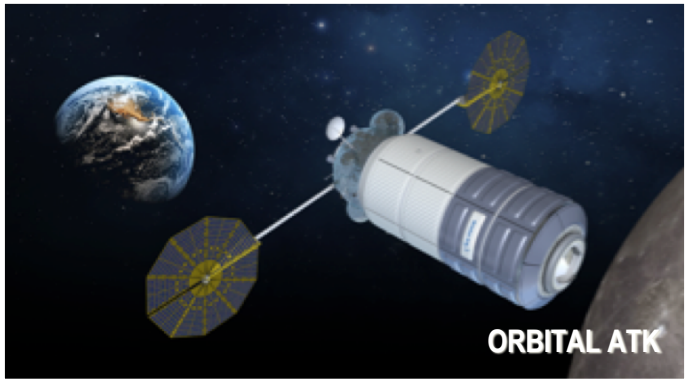
NASA team test the components of Saffire I and Saffire II



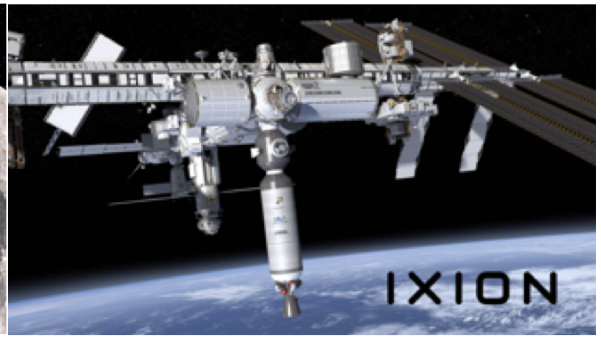
Greenwall prototype system - a public private partnership for Next STEP Habitation efforts

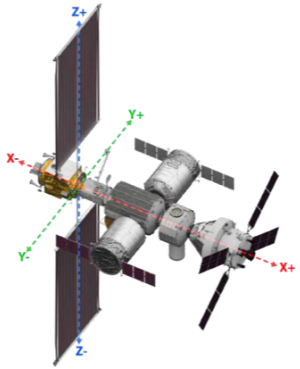
Human Exploration and Operations

Exploration Advanced Systems: Overview (continued)



NextSTEP Habitation Study Concepts



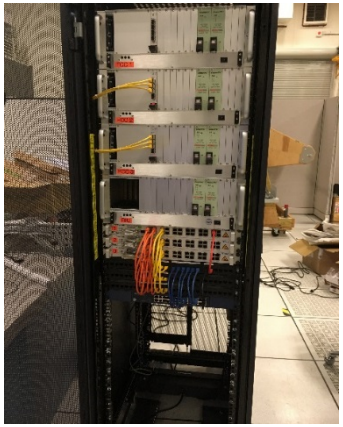


International concepts for contributions and utilization for gateway buildup in cislunar space

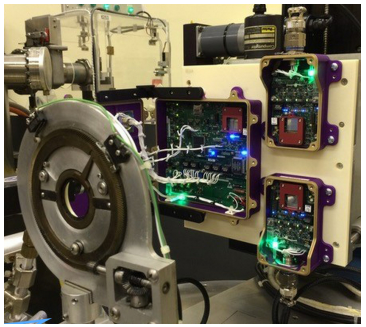
Human Exploration and Operations

Exploration Advanced Systems: FY 2018 and FY 2019 Plans

- Continue development and testing of capabilities needed for the next phase of habitation elements under LOP-G
  - Includes radiation sensors and protection, software for autonomous mission operations, avionics, and power systems
- Ground testing of full size NextSTEP-2 BAA prototype cislunar habitats
- Deliver prototype systems for a cislunar habitat for demonstration and use on ISS
  - Begin development of flight demonstration hardware for oxygen recovery from CO2 and water and microbial monitors
- Accelerating life support systems to complete testing on ISS by the end of FY 2024
  - Evolve regenerative Environmental Control and Life Support Systems (ECLSS) hardware into more reliable options for atmosphere revitalization and water recycling
  - Develop advanced humidity condensate control technologies
  - Continue development of advanced waste management technologies and more capable on-orbit environmental monitoring systems



Mockup of Exploration System Testbed habitat for avionics software testing



Hybrid Electronic Radiation Assessor Flight System radiation monitor calibration at Brookhaven National Lab

Human Exploration and Operations

Exploration Advanced Systems:
FY 2018 and FY 2019 Plans (continued)

- Continue to advance life support systems that will directly feed into the small habitat
  - Utilize ISS as a testbed for exploration technologies through testing and use of next generation ECLSS and other Habitation Systems technologies
    - Including brine processor, a miniaturized spacecraft atmospheric monitor to detect hazardous chemicals, a universal waste management system (toilet), thermal amine CO2 removal system, urine and water processor upgrades
- Develop Saffire IV-VI to reduce risks associated with spacecraft fire safety
- Begin Bigelow Expandable Activity Module (BEAM) extended mission
- Lead integration of Crew Module Systems Ascent Abort-2 Flight Test Article for flight test in April 2019

Image of Saffire-II sample 7 ignited in space

Illustration of AA-2 concept

Exploration System Development

Orion
Space Launch System
Exploration Ground Systems

Human Exploration and Operations

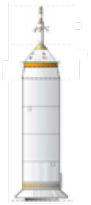
Exploration Systems Development: Overview

- Develop next generation capabilities for human exploration required to explore and expand human presence into our solar system
- Utilize development approach to assure integrated technical, schedule, and cost for all ESD programs (SLS/Orion/EGS) to maintain EM-1 and EM-2
  - EM-1 launch date is no earlier than (NET) December 2019 and represents a time frame that anticipates a majority of the hardware will be ready for final launch integration and flight
  - Schedule risk of 3-6 months exists and could result in June 2020 launch, and is principally focused in critical path areas related to core stage production and European Space Agency service module delivery
  - EM-2 is currently NET September 2022 to NLT April 2023 based on Orion Agency Baseline Commitment and the need to make ground system modifications following EM-1. Estimates will be updated as additional information is available regarding the EM-1 launch date
- Continuing Block 1B upgrades to SLS including Exploration Upper Stage (EUS) engineering design, development and procurement activities leading to EM-2 launch
  - Includes minor upgrades for the Orion vehicle and work required by EGS to modify the ground systems at KSC to accommodate increased vehicle height when EUS is added

Human Exploration and Operations

Exploration Systems Development: Integrated Manifest

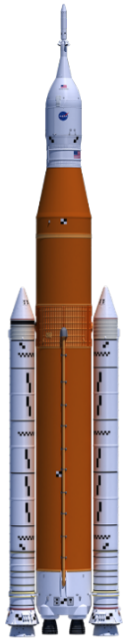
AA-2



Launch Abort System Test Article – Orion

Launch date - April 2019

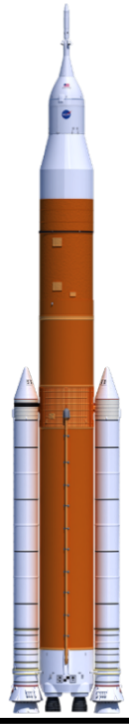
EM-1
First Lunar Flight Test



Uncrewed Orion SLS Block 1

Launch date – FY 2020

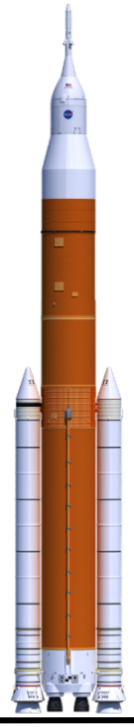
EM-2
First Lunar Crewed Flight



Crewed Orion SLS Block 1B

Launch date - 2023

EM-3
Second Lunar Crewed Flight



Crewed Orion SLS Block 1B

Launch date - 2024

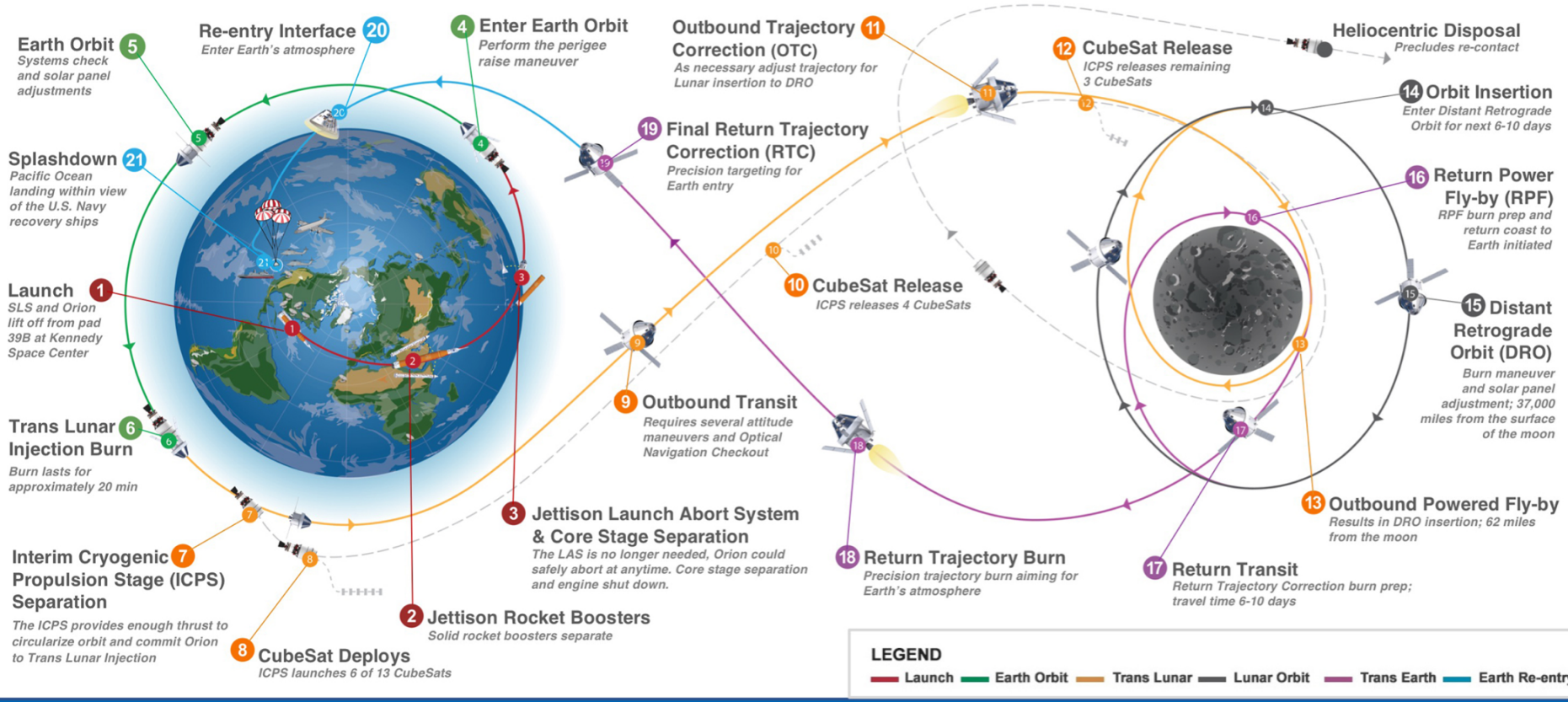
Human Exploration and Operations

Exploration Systems Development: EM-1 Mission Summary

EXPLORATION MISSION-1

National Aeronautics and Space Administration

The first uncrewed, integrated flight test of NASA's Deep Space Exploration Systems. The Orion spacecraft and Space Launch System rocket will launch from a modernized Kennedy spaceport



Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

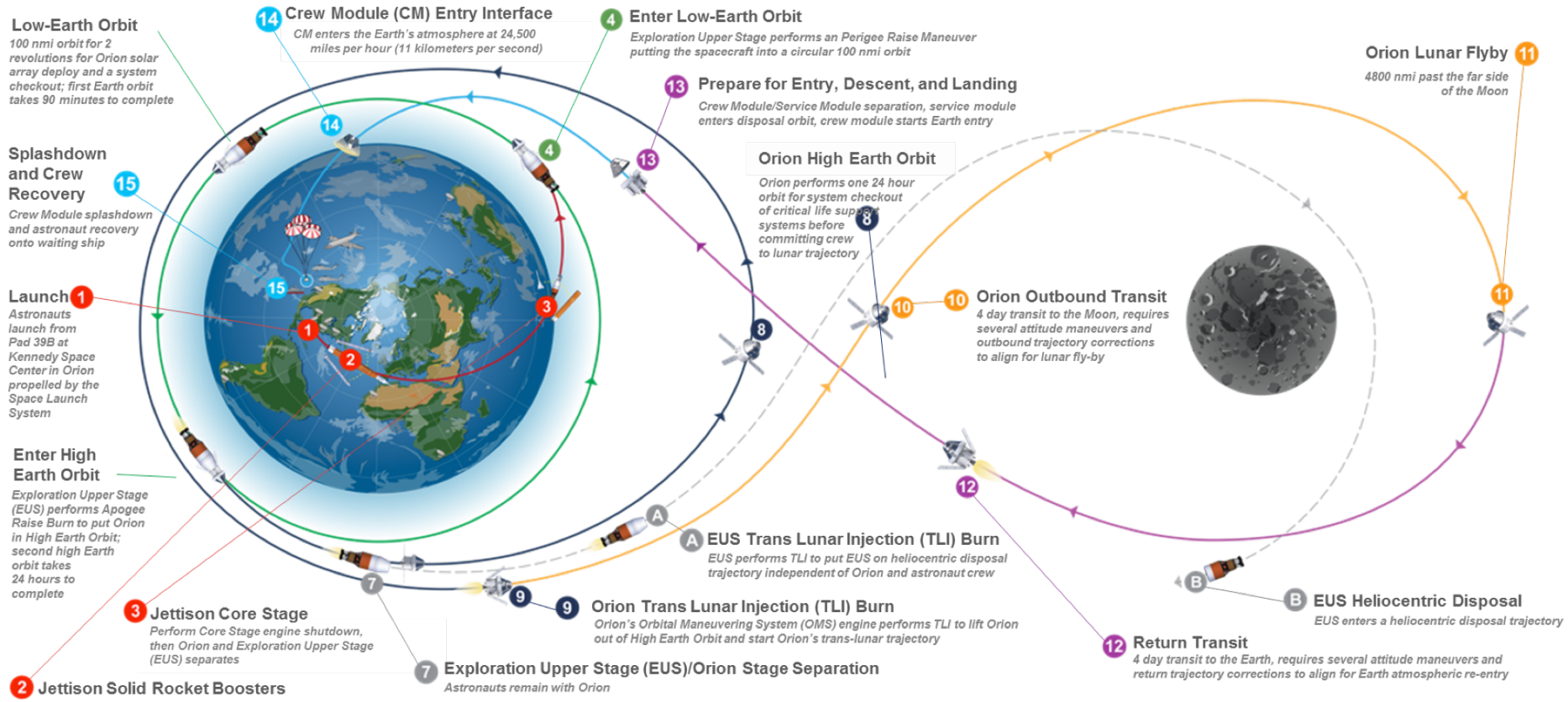
Human Exploration and Operations

Exploration Systems Development: EM-2 Mission Summary

EXPLORATION MISSION-2

National Aeronautics and Space Administration

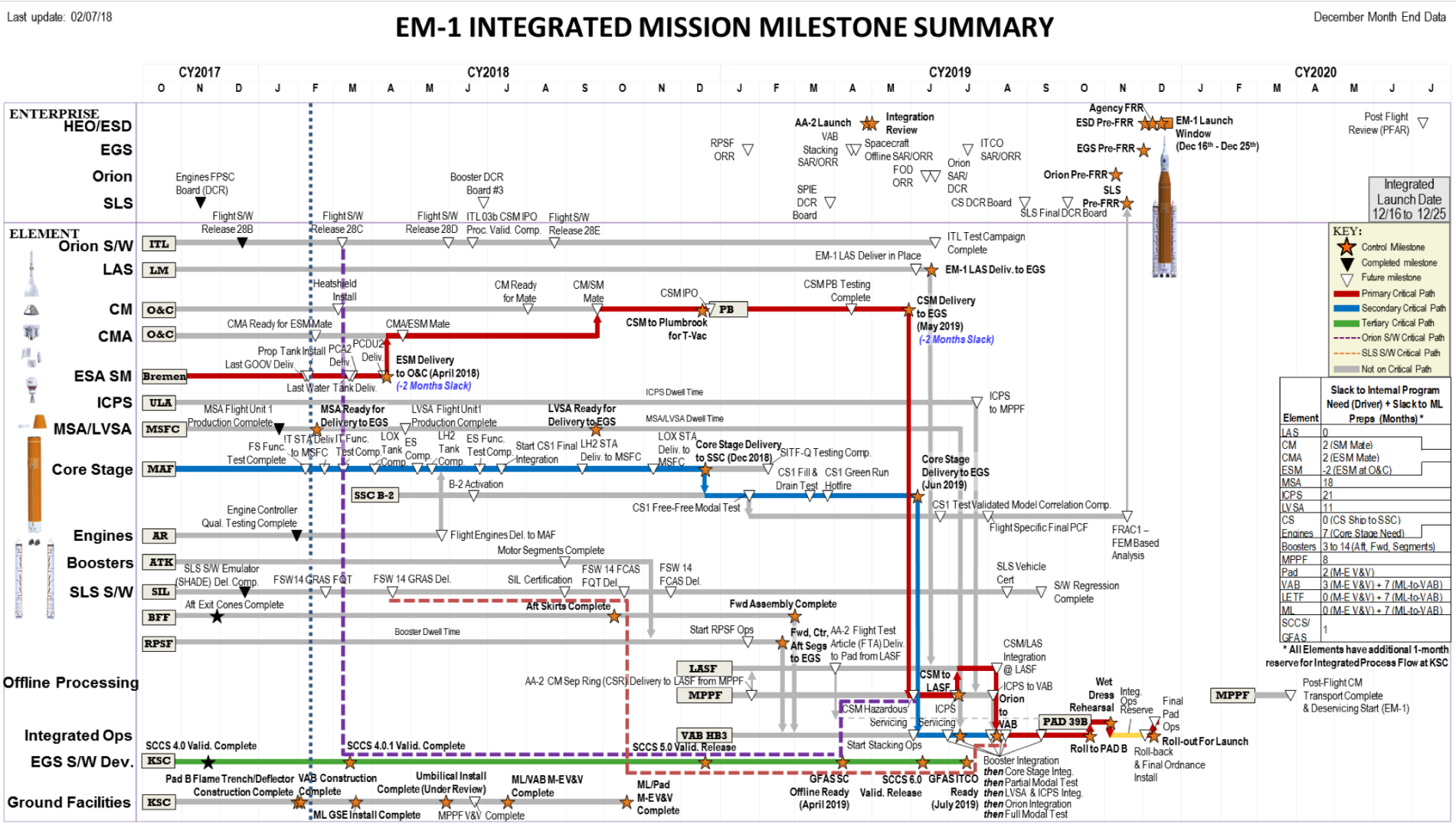
The first crewed, integrated flight test of NASA's Deep Space Exploration System, the Orion spacecraft and Space Launch System launching from a modernized Kennedy Spaceport.



4 astronauts - Total distance traveled: 1,090,320 km - Mission duration: 9 days – Re-entry speed 24,500 mph (Mach 32) – 9 metric ton Co-Manifested Payload deploy

Human Exploration and Operations

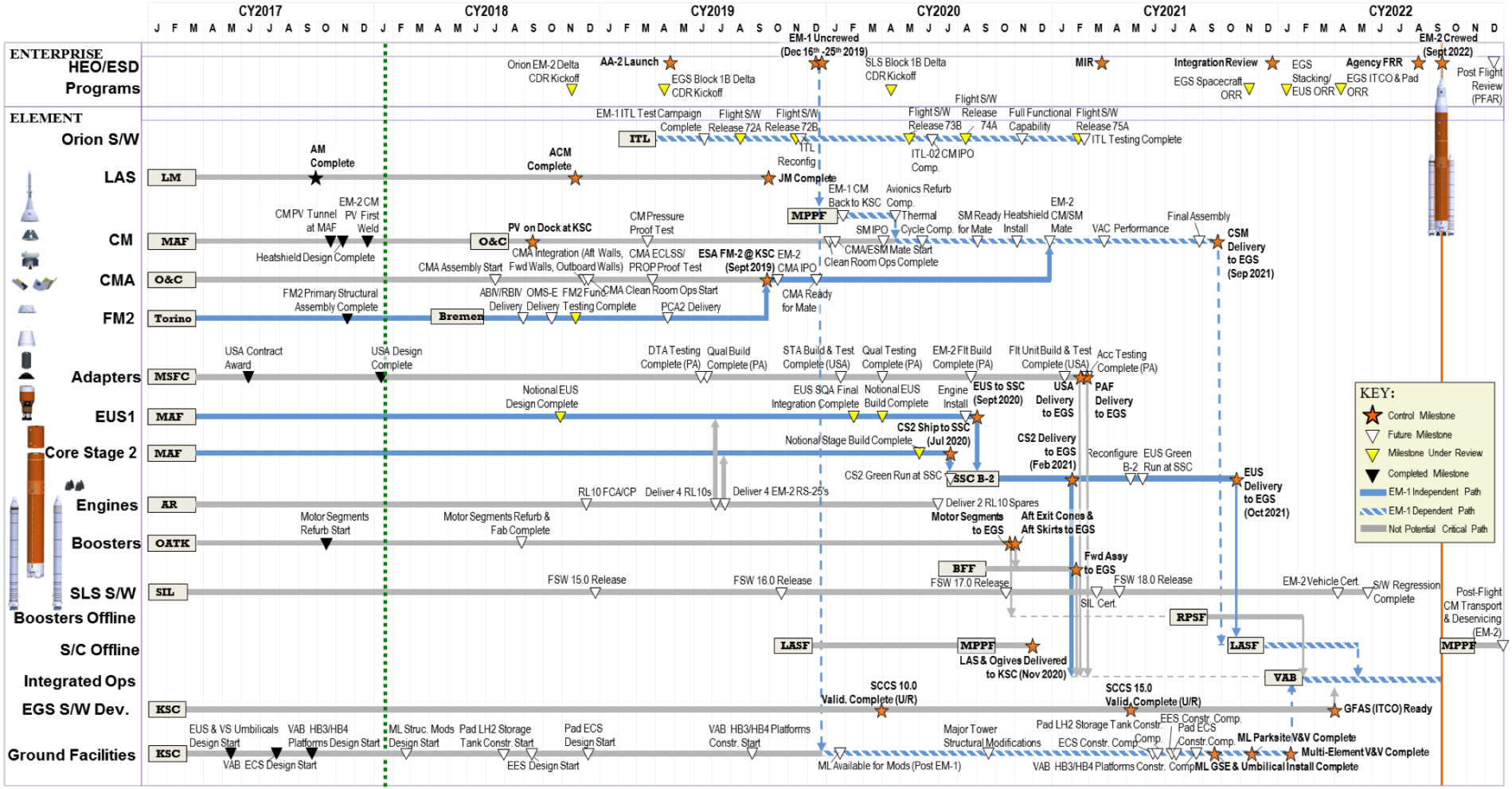
Exploration Systems Development:
EM-1 Integrated Mission Milestone Summary



Human Exploration and Operations

Exploration Systems Development:
EM-2 Integrated Mission Milestone Summary

DRAFT EM-2 INTEGRATED MISSION MILESTONE SUMMARY

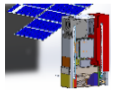


Human Exploration and Operations

Exploration System Development:

EM-1 Secondary Payloads - First Cubesats Delivered to Deep Space

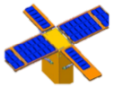
LUNAR FOCUS



- **LUNAr polar Hydrogen Mapper (LunaH-Map)**
  - Payload Developer: Arizona State University (ASU)
  - Objective: Perform neutron spectroscopy of lunar surface to determine H abundance
  - Mission Destination: Lunar Orbit

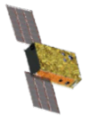
- **Lunar Flashlight**
  - Payload Developer: Jet Propulsion Laboratory
  - Objective: Search for lunar surface ice deposits using near-IR band lasers
  - Mission Destination: Lunar Orbit

- **Lunar IceCube**
  - Payload Developer: Moorehead State University
  - Objective: Prospect for water (ice, liquid & vapor) & other lunar volatiles using IR spectrometer
  - Mission Destination: Lunar Orbit

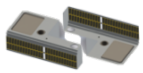


- **LunIR**
  - Payload Developer: Lockheed Martin Space Systems
  - Objective: Collect IR imaging of Lunar Surface
  - Mission Destination: Heliocentric via Lunar Flyby

- **Outstanding Moon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor (OMOTENASHI)**
  - Payload Developer: JAXA
  - Objective: Develop world's smallest lunar lander and observe lunar radiation environment
  - Mission Destination: Lunar Surface

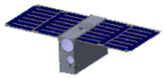


- **EQUULEUS**
  - Payload Developer: JAXA
  - Objective: Characterize radiation environment in geospace by imaging the Earth's plasmasphere
  - Mission Destination: Earth-Moon L2

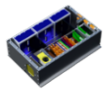


- **Cislunar Explorers**
  - Payload Developer: Cornell University
  - Objective: Compete in the **Lunar Derby** for Achieving Lunar Orbit and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

OTHER DEEP SPACE ENABLING

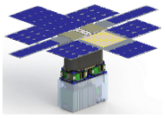


- **ArgoMoon**
  - Payload Developer: ASI
  - Objective: Provide photography of EM-1 Mission, detailed imagery of ICPS as well as demonstrate image system operability
  - Mission Destination: Elliptical Earth Orbit (ICPS proximity)



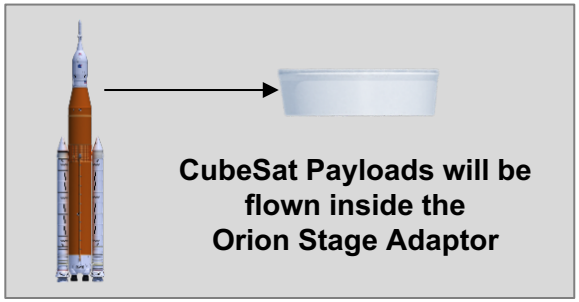
- **Team Miles**
  - Payload Developer: Fluid & Reason, LLC
  - Objective: Compete in the **Deep Space Derby** for Furthest Communication Distance from Earth prize
  - Mission Destination: Deep Space

- **CU-E3**
  - Payload Developer: University of Colorado
  - Objective: Compete in the **Deep Space Derby** for Best Burst Data Rate, Largest Aggregate Data Volume Sustained over time, Spacecraft Longevity and Furthest Communication Distance from Earth prizes
  - Mission Destination: Deep Space



- **Near Earth Asteroid Scout (NEA Scout)**
  - Payload Developer: Marshall Space Flight Center
  - Objective: Perform target detection, reconnaissance and close proximity imaging of a NEA
  - Mission Destination: a Near Earth Asteroid (within ~1.0 AU distance from Earth)

- **BioSentinel**
  - Payload Developer: Ames Research Center
  - Objective: Quantify DNA damage from space radiation environment
  - Destination: Heliocentric Trajectory



Human Exploration and Operations

Orion: Overview

- Continues to develop and produce spacecraft capable of carrying humans beyond LEO with ability to conduct in-space operations to support nation's goal for space exploration that expands human presence deeper into the solar system through a sustainable human and robotic spaceflight program
  - Four vehicles currently in assembly and test
- Enables deep space human exploration mission – Orion's architecture and design support multiple exploration scenarios
- Utilizes capabilities across the country to enhance leadership in human space flight operations including
  - Conduct structural test program at Lockheed Martin in Denver, CO
  - Conduct launch abort system test firing at Orbital ATK in Promontory, UT
  - Qualification of ESA Service Module propulsion at White Sands, NM
  - Parachute testing at U.S. Army Yuma Proving Ground in Yuma, AZ
  - Acoustic testing at GRC Plum Brook station in Sandusky, OH
- Supports international cooperation
  - Partnering with ESA to provide European Service Module (ESM) design and flight for EM-1 and EM-2
  - Initial discussions with ESA towards providing ESM contributions for future EM launches beyond EM-2

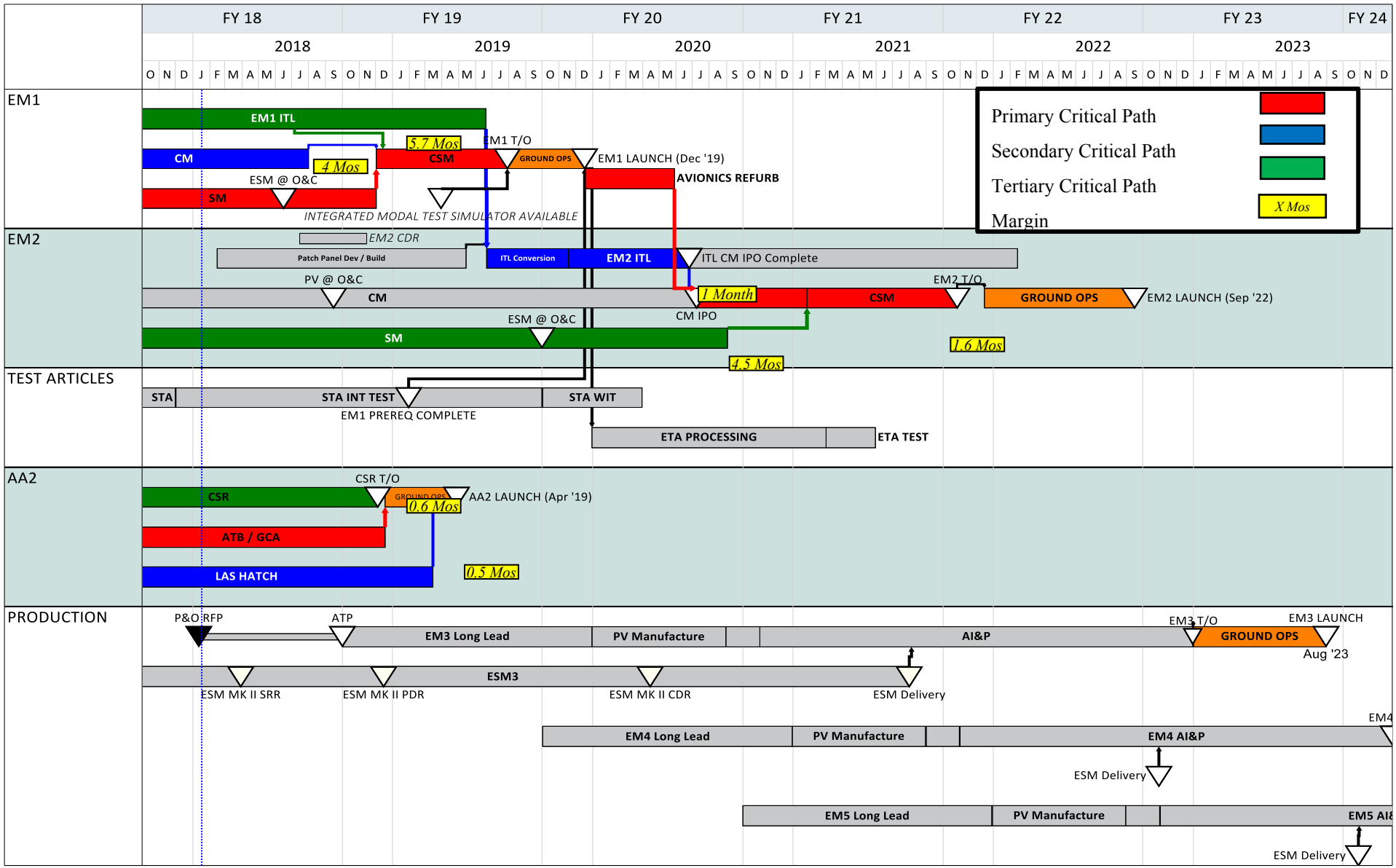
Human Exploration and Operations

Orion: Overview (continued)

- Making substantial progress towards EM-1 flight
- Commenced initial manufacturing for EM-2 crewed flight
- Capitalize on Agency investments through partnerships to leverage hardware and technology development to meet Orion needs
  - AES: Universal Waste Management System design, development, test and evaluation (DDT&E) including ISS demo; advanced radiation monitoring; and docking hatch DDT&E
  - SCaN and STMD: install and operate optical communications on EM-2 enabling significantly higher deep space communication levels
  - STMD: successful partnership to integrate advanced heat shield compression pad technology for EM-1 and EM-2; high temperature and high strength compression pads allow lighter Orion structure
- Continue to share test and analysis data with CCP - enabling reductions in their test programs where applicable
- Continue to meet program commitments by identifying risks and assuring integrated technical, schedule, and cost approach
- Optimizing future production contracts to emphasize cost incentive and fixed price structures

Human Exploration and Operations

Orion: Strategic Schedule



Human Exploration and Operations

Orion: FY 2018 Plans

- Complete production and assembly of EM-1 Crew Module Adapter
- Install heat shield on the Crew Module
- Take delivery of ESA Service Module at KSC
  - Mate ESM to the Crew Module Adapter to complete Service Module assembly
- Complete testing of Flight Software functions such as nominal missions, ascent aborts (AA), safe mode, entry decent landing, optical navigation, maneuver plan management, solar array controls, fault detection and isolation
- Continue building first crewed mission spacecraft for EM-2
- Complete Crew Module primary structure welding at MAF
- Start EM-2 Crew Module and Service Module assembly and integration
- Complete assembly of AA-2 Crew Module and Separation Ring in preparation for FY 2019 AA-2 test flight
- Complete eight test programs on the Structural Test Article

EM-1 Crew Module at KSC – moving between work stands

ESM propulsion module testing at White Sands Test Facility

Human Exploration and Operations

Orion: FY 2019 Plans

- Complete integrated EM-1 Crew Module/Service Module testing at KSC
- Deliver AA-2 test article to KSC and complete final assembly and stacking operations
- Perform AA-2 flight test in April 2019
- Complete integrated testing of EM-1 Crew Module and Service Module at GRC's Plum Brook Station
  - Thermal vacuum, thermal balance and electromagnetic interference
- Complete mating of Launch Abort System (LAS) to Orion Crew and Service Module (SM)
- Deliver Orion Crew and Service Module to EGS
- Release EM-1 final software and complete test campaign to verify and validate the software for use during EM-1 mission
- Complete structural test campaign in Denver and ship test article to LaRC for water impact testing
- Complete Crew Module secondary structure and component assembly for EM-2

Illustration of AA-2 concept

CM and ESM Structural Test in Denver

1st weld of EM-2 - completed

Human Exploration and Operations

Orion: Schedule/Milestones

• EM-1 ESA Service Module On Dock	June 2018
• SM Initial Power-on Test Completed	September 2018
• SM Thermal Cycle Test Completed	September 2018
• EM-2 Crew Module On Dock	September 2018
• SM Acoustics Test Completed	November 2018
• EM-2 Critical Design Review	November 2018
• EM-1 SM Mate with CM	December 2018
• EM-2 System Integration Review	February 2019
• AA-2 Flight Test	April 2019
• EM-1 Completed CSM Available for EGS	July 2019
• EM-1 Mate LAS to CSM	October 2019
• EM-2 ESA Service Module On Dock	September 2019
• EM-1 Launch Readiness	December 2019
• EM-2 Available for Ground Operations	September 2021
• EM-2 ORR/FRR	NET August 2022
• EM-2 Launch	NET September 2022

Human Exploration and Operations

Space Launch System: Overview

- Evolve heavy lift launch capability using block upgrades to deliver large crew, cargo, and transfer and delivery systems to exploration destinations
  - Near-term: deliver a launch system capable of delivering more than 26 metric tons beyond low-Earth orbit and on to the moon (also known as trans-lunar injection, TLI) to demonstrate spacecraft systems performance on an initial un-crewed flight in the lunar vicinity (EM-1)
  - Follow-on: deliver a launch system with an EUS capable of delivering more than 37 metric tons to TLI to significantly expand deep space mission capability as early as budget allows
  - Future plans: deliver a launch system with an EUS and advanced boosters capable of delivering more than 45 metric tons to TLI to further expand deep space mission capability
- Leverage extensive experience with heavy lift vehicles and advanced manufacturing capabilities to build and operate SLS at lower costs than previous heavy lift launch systems

Four RS-25 flight engines with their new Engine Controller Units (ECU) preparing for shipment to NASA's Michoud Assembly Facility in New Orleans

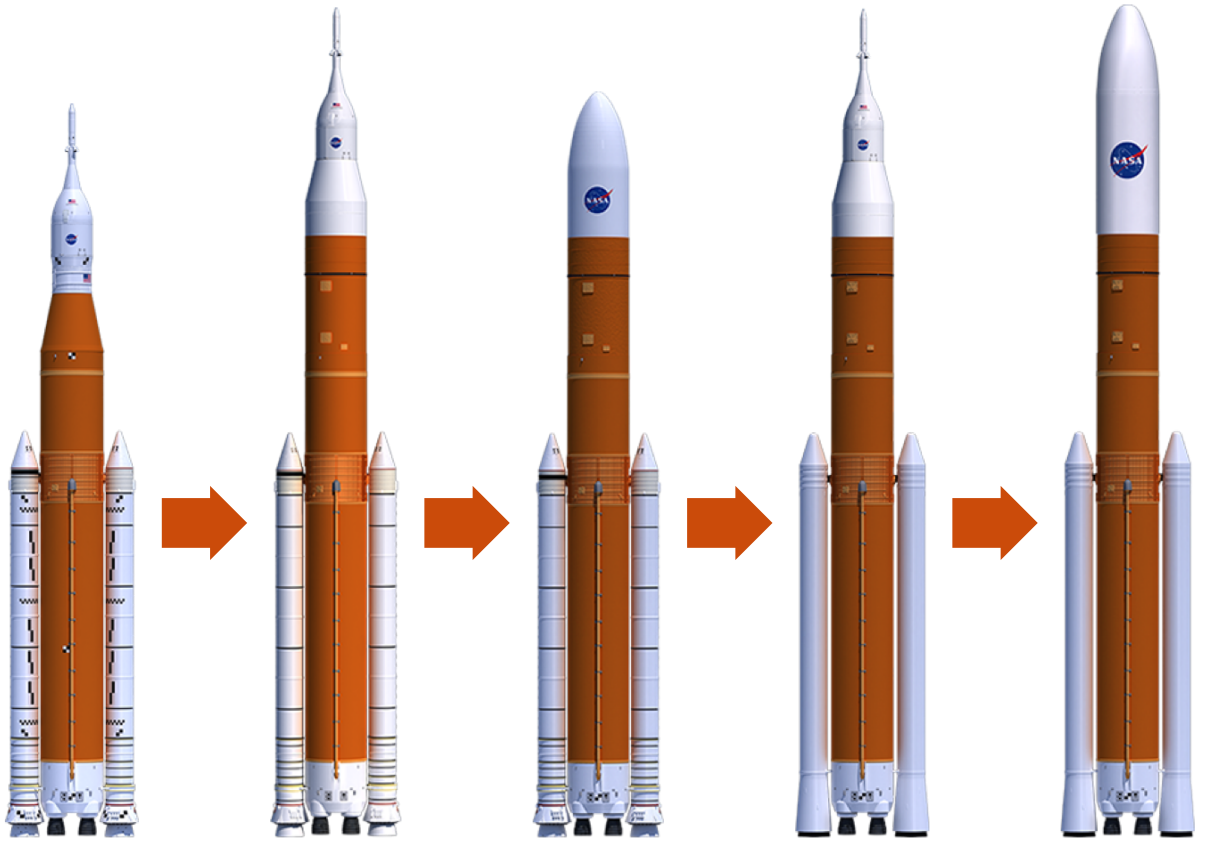
Interim Cryogenic Propulsion Stage (ICPS) at KSC, packed inside a canister, exits United Launch Alliance (ULA) for its move to the Space Station Processing Facility

Space Launch System Lift Capabilities

	SLS Block 1	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Payload to TLI/Moon	> 26 t (57k lbs)	34–37 t (74k–81k lbs)	37–40 t (81k–88k lbs)	> 45 t (99k lbs)	> 45 t (99k lbs)
Payload Volume	N/A**	10,100 ft^3 (286m^3)**	18,970 ft^3 (537 m^3)	10,100 ft^3 (286m^3)**	31,950 ft^3 (905 m^3)

Trans-Lunar Injection (TLI) is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. A spacecraft performs **TLI** to begin a lunar transfer from a low circular parking orbit around Earth.

The numbers depicted here indicate the mass capability at the Trans-Lunar Injection point.

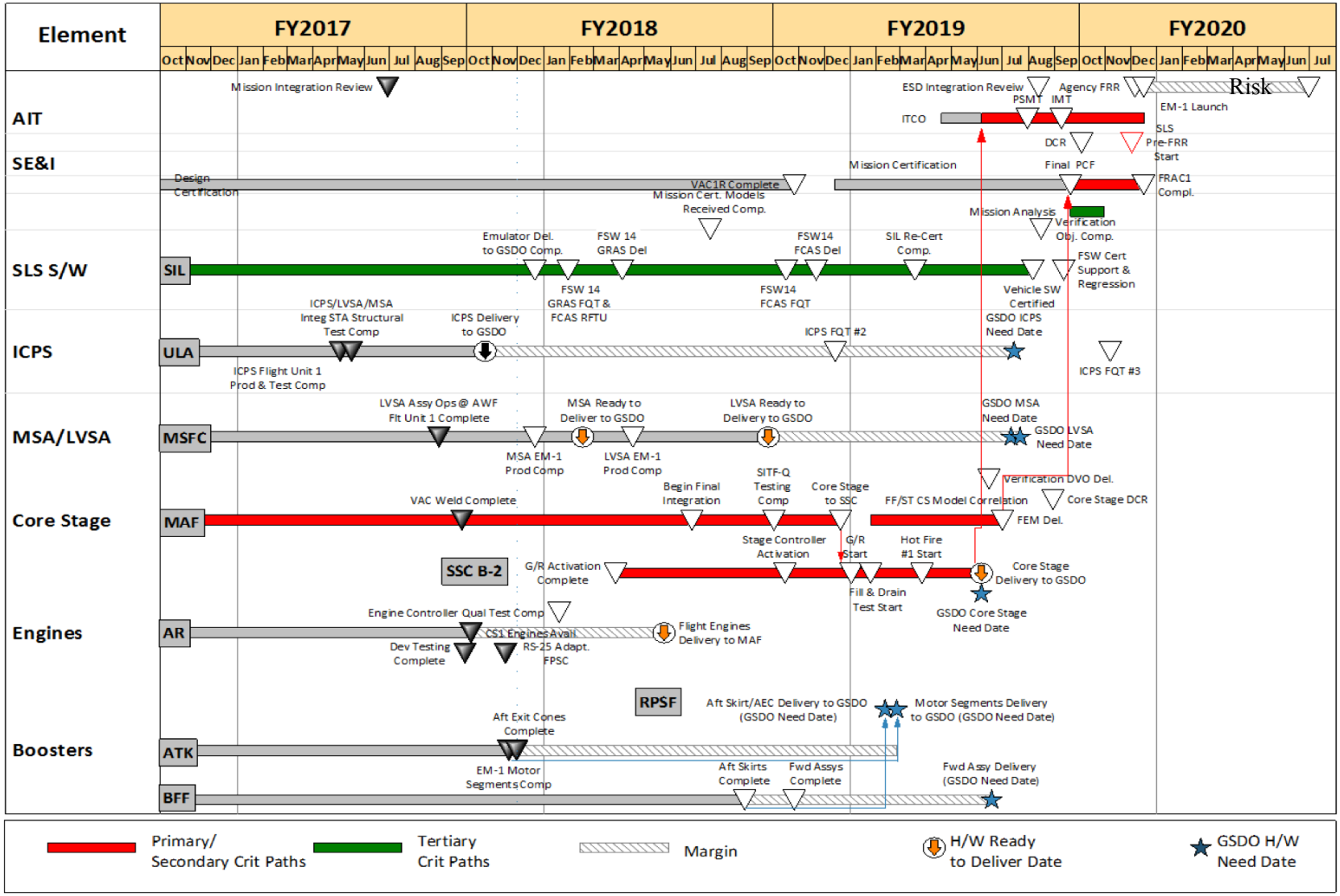


** Not including Orion/Service Module volume

	SLS Block 1	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Maximum Thrust	8.8M lbs	8.8M lbs	8.8M lbs	11.9M lbs	11.9M lbs

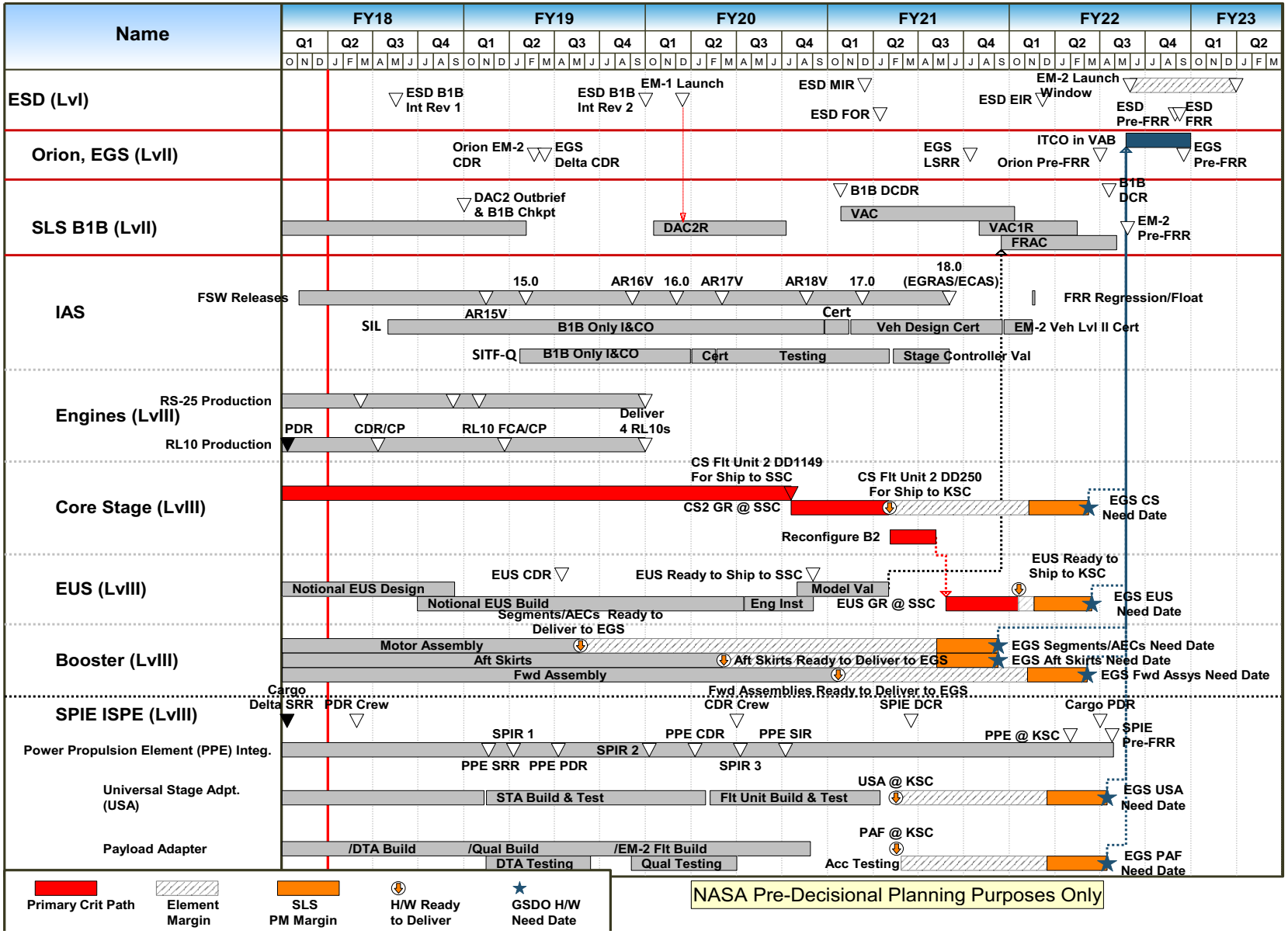
Human Exploration and Operations

Space Launch System: EM-1 Integrated Schedule



Human Exploration and Operations

Space Launch System: Draft EM-2 Summary Schedule



NASA Pre-Decisional Planning Purposes Only

Human Exploration and Operations

Space Launch System: EM-1 Schedule/Milestones

• Engine section Structural Test Article (STA) shipped to MSFC	April 2017
• Interim cryogenic propulsion stage (ICPS) accepted by EGS	October 2017
• Orion stage adapter to EGS	February 2018
• Intertank STA ship to MSFC	March 2018
• Launch Vehicle Stage Adapter to EGS	August 2018
• LH2 STA tank ship to MSFC	September 2018
• Liquid Oxygen (LOX) STA tank ship to MSFC	October 2018
• Flight software release	November 2018
• EM-1 booster aft skirts to EGS	February 2019
• EM-1 booster motor segments to EGS	February 2019
• EM-1 booster forward assemblies to EGS	March 2019
• Green run testing at Stennis Space Center (SSC)	March/April 2019
• Core stage delivery to EGS	June 2019
• Block 1 design certification review	October 2019
• EM-1 Launch Readiness	December 2019

Human Exploration and Operations

Space Launch System: FY 2018 Plans

Stages	Complete Marshall Space Flight Center (MSFC) test stands 4697 LOX, 4693 Liquid Hydrogen (LH_2), and intertank
Stages	Complete core stage forward and aft major joints
Stages	Completed testing of engine section Structural Test Article (STA), complete assembly of intertank, LH2 tank, and LOX tank STAs and ship to MSFC
Engines	Continue production on RS-25 engines under restart contract, continue production of RL-10 engines for EUS
Engines	Complete assembly and acceptance of EM-2 (EM-1 contingency) engines 2063, 2047, and 2059
Engines	Completed RS-25 engine controller unit qualification testing
Booster	Complete EM-1 aft skirt work
Booster	Completed casting EM-1 motor segments
SPIE (Adaptors)	Deliver Orion Stage Adaptor (OSA) and Launch Vehicle Stage Adapter to EGS
SPIE (ICPS)	Delivered ICPS flight unit to EGS

Orion Stage Adaptor with CubeSat Brackets

Core Stage Pathfinder

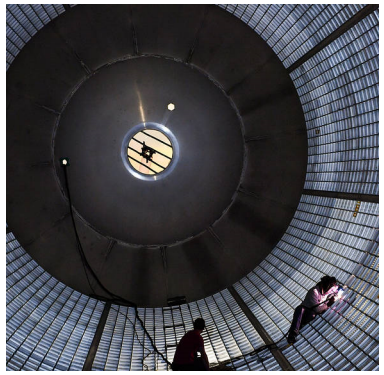
700 Ton Shackle at B2 Test Stand

Human Exploration and Operations

Space Launch System: FY 2019 Plans

Core Stage	Complete structural qualification testing of the intertank, LH_2 tank, and LOX tank
Core Stage	Complete core stage assembly and ship to SSC for green run testing
Core Stage	Complete core stage green run testing
Core Stage	Deliver core stage to EGS
Engines	Continue RS-25 restart and RL-10 EUS production
Engines	Complete manufacture of last EM-2 (EM-1 contingency) engine 2062
Engines	Complete manufacture of EM-2 RL-10 EUS engines
Booster	Complete forward assemblies and deliver to EGS
Booster	Deliver aft skirts to EGS
Booster	Complete finalization of EM-1 motor segments and deliver to EGS
SPIE	Complete SPIE Block 1 design certification review
SE&I	Certify flight software and avionics for flight
Program	Complete Program Block 1 design certification review

Orion Stage Adaptor STA loading into Super Guppy



Inside Hydrogen Tank Completing Plug Welds

Moving Qual Hydrogen Tank

Human Exploration and Operations

Exploration Ground Systems: Overview

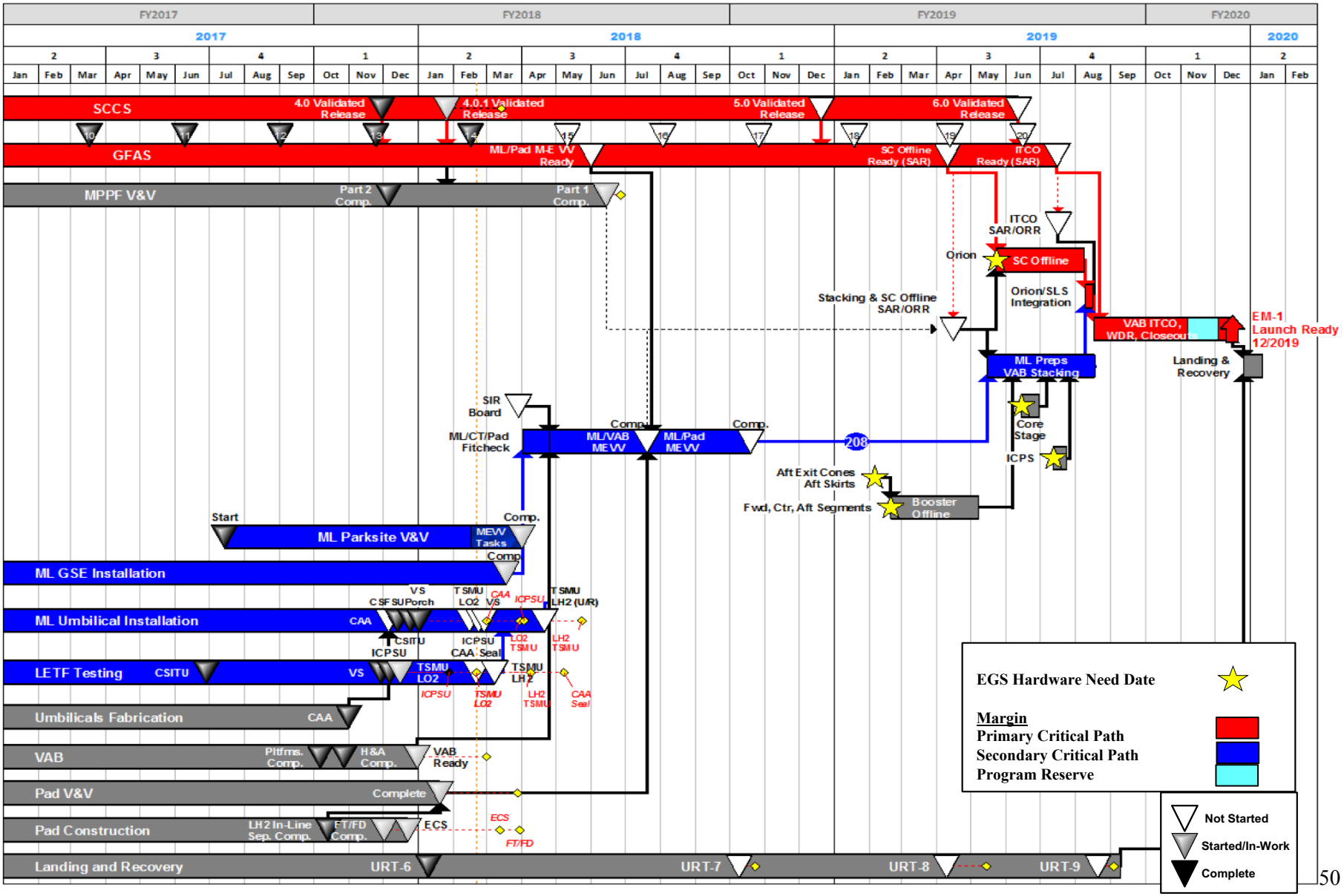
- Enable SLS and Orion ground processing and launch infrastructure to support integrated launch schedule
- Implement strategies and efficiencies to enable sustainable spacecraft and launch vehicle processing, operations, and recovery
- Prepare ground systems infrastructure for operations required to assemble, and launch SLS and Orion
- Recover Orion and astronaut crews as required through effective partnerships with the U.S. Navy

Ignition Overpressure/Sound Suppression System Wet Flow Test at Launch Pad 39B

KSC's NASA Recovery Team and the U.S. Navy pull the Orion test article in by a winch line USS Anchorage's well deck during Underway Recovery Test 6

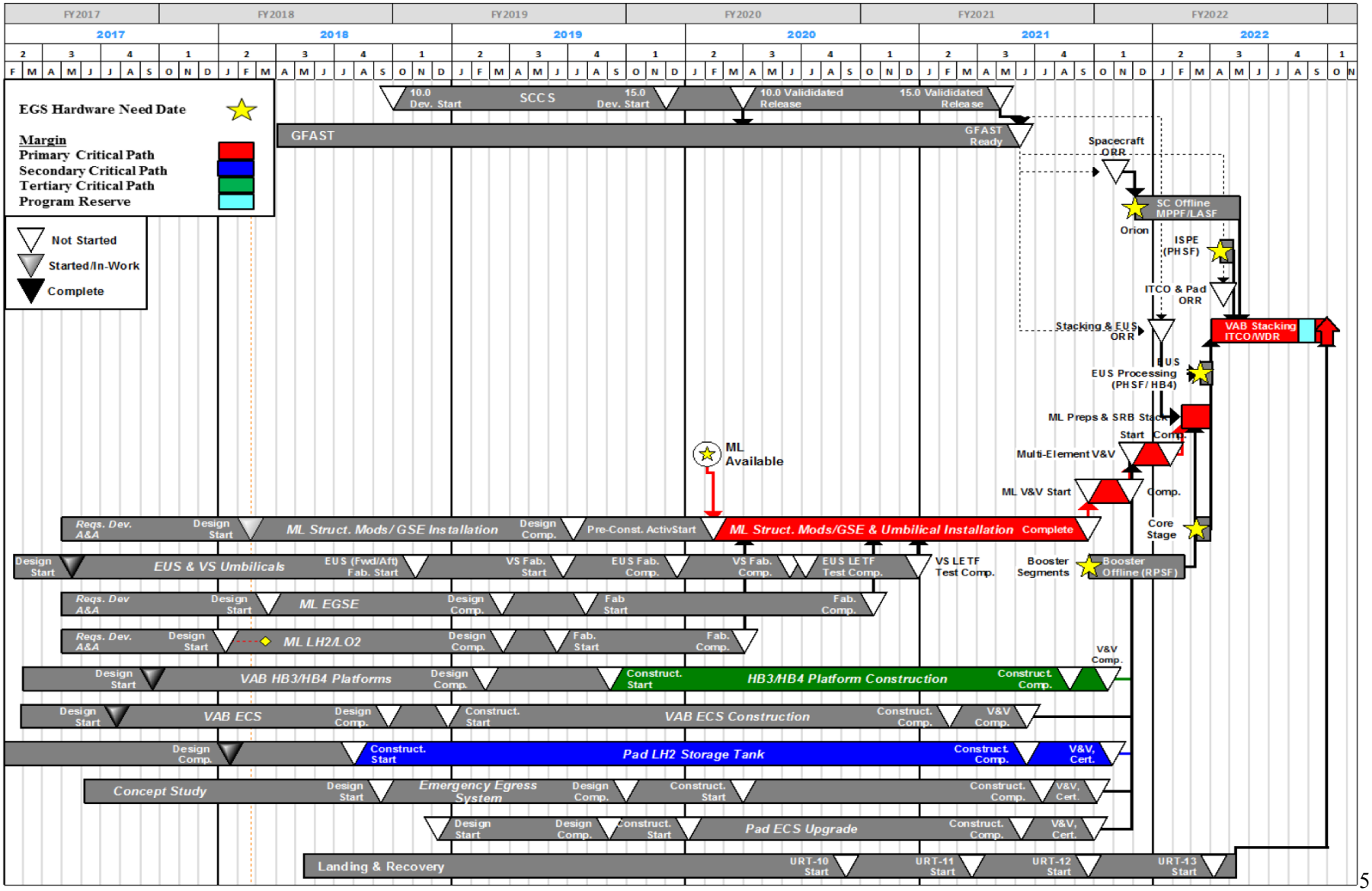
Human Exploration and Operations

EGS: EM-1 Critical Path Summary (Schedule Baseline)



Human Exploration and Operations

EGS: EM-2 Critical Path Summary (Schedule Baseline)



Human Exploration and Operations

Exploration Ground Systems: EM-1 Schedule/Milestones

• Complete VAB Environment Control System	February 2018
• Complete VAB Verification and Validation (V&V)	March 2018
• Complete program System Integration Review	March 2018
• Launch Equipment Test Facility umbilical testing	March 2018
• Ready to roll Mobile Launcher to Pad	April 2018
• Installation of umbilicals on the Mobile Launcher	May 2018
• Mobile Launcher/VAB Multi-Element V&V	July 2018
• GFAST Ready for Integrated Test and Checkout	July 2018
• Start of integrated operations	May 2019
• Start Solid Rocket Booster (SRB) stacking	June 2019
• Start of Core Stage mate to SRB mate	July 2019
• Begin stacking of Orion to SLS in High Bay 3	August 2019

Human Exploration and Operations

Exploration Ground Systems: EM-1 Schedule/Milestones (continued)

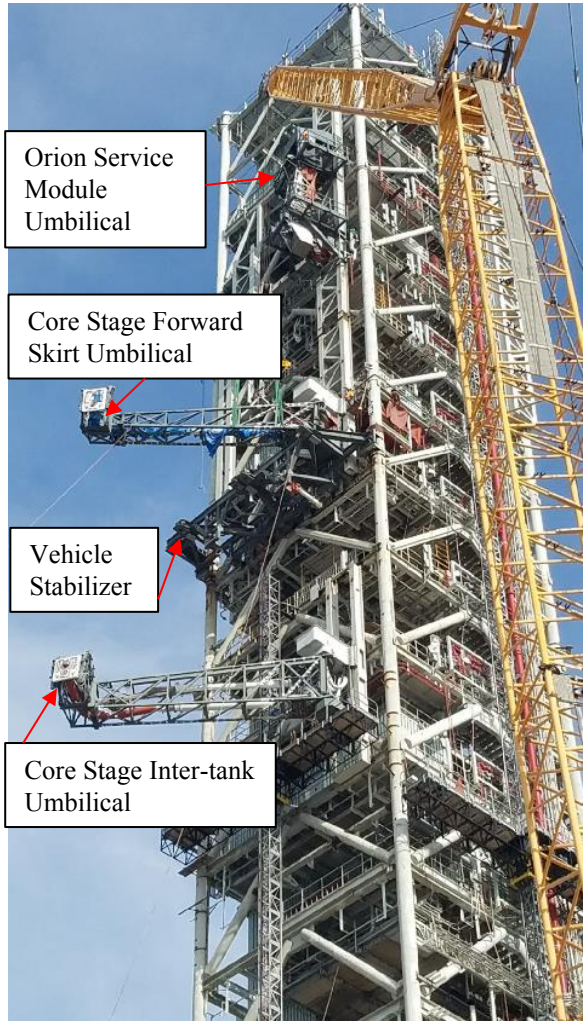
- Start ICPS to Launch Vehicle Stage Adapter mate — August 2019
- Complete integrated vehicle stacking/ready for vehicle power — August 2019
- Start rollout for Wet Dress Rehearsal — October 2019
- EM-1 Launch Readiness — December 2019

Modifications are underway at the Launch Complex 39 turn basin wharf to prepare for the arrival of the massive SLS core stage aboard the barge Pegasus

Human Exploration and Operations

Exploration Ground Systems: FY 2018 Plans

- Complete System Integration Review
- Complete software testing and certify readiness to support multi-element V&V
- Completed Underway Recovery Test-6 (URT-6)
- Complete system testing on Mobile Launcher which includes; pneumatics facilities testing, GSP Channel 4 testing and umbilical channelization
- Complete Mobile Launcher Ground Support Equipment (GSE) and GSE umbilical installation
- Complete launch accessory swing testing
- Begin spacecraft offline process to validate all systems' software and hardware
- Validate VAB and Pad B are ready for Mobile Launcher and flight hardware
- Deliver 50k gallons of Liquid Hydrogen to LC39 with an additional 50k gallons delivered to Space Launch complex-37B to conduct a scrub turnaround test



Install Launch umbilicals on Mobile Launcher which will provide power, communications, coolant, and fuel to SLS

Human Exploration and Operations

Exploration Ground Systems: FY 2019 Plans

- Complete Multi-Element V&V for Mobile Launcher/Pad
- Begin spacecraft offline process to validate all systems' software and hardware
- Begin stacking and integration of Crew Service Module in the Launch Abort System Facility
- Complete Booster stacking and Core Stage mate
- Conduct integrated operations with SLS Core Stage and Orion Crew Service Module at KSC
- Begin preparation for spaceflight readiness for Orion crew service module and vehicle
- Complete verification of all ground systems and vehicle interfaces required for launch (except Mobile Launcher to launch pad)
- Conduct three underway recovery test (URTs) off the coast of San Diego, CA
  - URT-7 - October 2018
  - URT-8 - April 2019
  - URT-9 - July 2019

International Space Station

Human Exploration and Operations

International Space Station: Overview

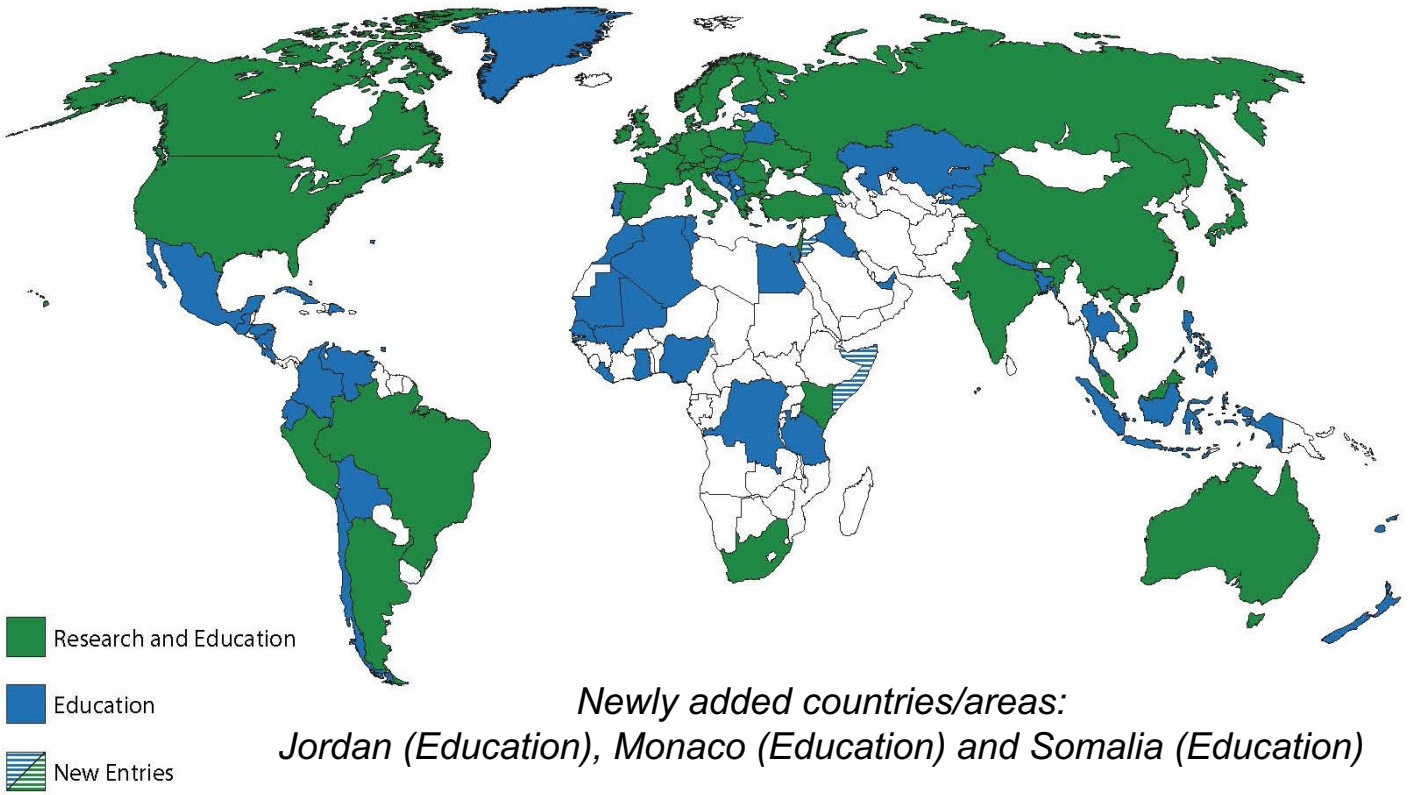
- Enable long duration spaceflight beyond LEO by
  - Providing human health and performance research and risk mitigation
  - Evaluating extended performance of equipment critical to long-duration flight, such as habitation system demonstrations
    - Testing hardware's ability to survive in the space environment
    - Determining life-limiting issues and repair capabilities
    - Evaluating upgrades to improve performance
- Form a key element of U.S. leadership across the globe for human spaceflight and exploration
  - NASA continues to lead space agencies around the globe (Japan, Canada, Europe, Russia) in an international endeavor to perform research in LEO and to extend human presence into the solar system

Human Exploration and Operations

International Space Station: Overview (continued)

- Maximize utilization and conduct world class science to improve life on Earth
  - Implement research priorities through guidance from 2011 National Academies decadal survey, and its 2018 midterm assessment, NASA Advisory Committee, and Space Studies Board subcommittee
  - Utilize competitive solicitation process and peer review to ensure high quality research
  - Continue streamlining processes to maximize crew time available for research
  - Advance international collaborations in space life and physical sciences research
  - Include larger ISS research community by developing and implementing new and innovative approaches for science program management through open science initiatives
  - Support activities for SMD, STMD, HRP, AES, Biological and Physical Science (BPS), Exploration Systems Development (ESD), and National Lab (NL) customers
- Maintain research and commercialization as top priorities, including safety of crew and vehicle, while fulfilling international partner obligations
  - Enable commercial demand driven market in LEO
  - Expand partnerships on ISS
  - Plan to end direct U.S. financial support in 2025, after which NASA to rely on commercial partners for LEO research and technology demonstration requirements

ISS Utilization Statistics: Expeditions 0-50
December 1998 – April 2017



Newly added countries/areas:
Jordan (Education), Monaco (Education) and Somalia (Education)

101 highlighted countries and areas have participated in ISS Research and Education Activities

PSF Approved November 2017. SSCB Approved January 2018. Pending MCB Approval

Human Exploration and Operations

International Space Station: Supporting the Commercial Market

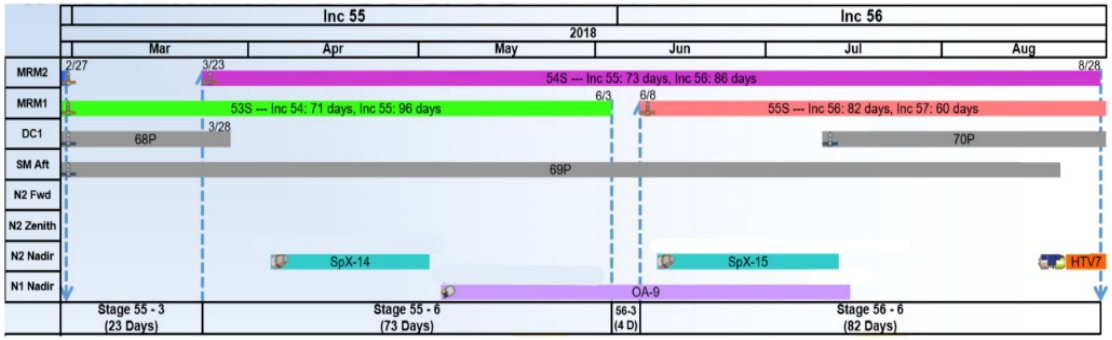
- Space Transportation
  - Vehicle launches to ISS accounted for ~13% of global launch market (2017, 12 of ~92 launches)
  - Development and operations of domestic ISS commercial cargo providers (Space Exploration Technologies Corporation (SpaceX), Orbital ATK, and Sierra Nevada) have lowered launch costs worldwide through increased competition; secured market through 2024 with Commercial Resupply Services (CRS)-2 award
- Utilization and Application
  - Center for the Advancement of Science in Space (CASIS) has expanded commercial use of ISS through private partnerships
    - FY 2017, ISS National Lab (NL) set new records for R&D payload upmass and utilization: 76 payloads were launched to the ISS NL (a 31% increase over FY 2016), carrying more than 100 individual experiments
    - Payloads included -Fortune 500 customers Merck, Eli Lilly & Co., and Procter & Gamble as well as notable new payloads - Fortune 100 company Hewlett Packard Enterprise and nonprofit Michael J. Fox Foundation for Parkinson's Research
      - Microgravity in space may allow bigger, more regular LRRK2 protein crystals to grow-this information could help scientists design optimized therapies against LRRK2, a key target in the pursuit of a Parkinson's cure

Human Exploration and Operations

International Space Station: Increment 55 and 56

Increment 55: 96 days

- Stage 55-3: 52S undock to 54S dock: 23 days
- Stage 55-6: 54S dock to 53S undock: 73 days
- US EVAs (*March and May*)
  - US EVA N3 External Wireless Comm (EWC) & Camera Port 8 (CP8)
  - US EVA N2F EWC
  - US EVA PFCS Relocate & CP13
- Cargo vehicles:
  - SpaceX-14
  - Progress 68P Undock
  - Orbital ATK-9
- Science/Utilization:
  - Human Research Facility (HRF) Centrifuge
  - Veggie Ponds
  - Plant Habitat 01
  - Divert Unwanted Space Trash (DUST)
  - NanoRacks RemoveDebris (NR RemDeb)
  - Robonaut (return SpX-14)
- Maintenance/Outfitting:
  - RPCM R&Rs
  - Umbilical Interface Assembly (UIA) R&R
  - PMA3 Inter-Module Ventilation (IMV) Duct Install
  - Bigelow Expandable Activity Module (BEAM) Stowage



	Increment 55	Increment 56
Utilization	• Airway Monitoring – Lab Session (ESA) • ACME E-Field Flames • Marrow (CSA) • Probiotics (JAXA) • SpX-14: APEX-06 • SpX-14: Invitrobone (ESA) • SpX-14: Mouse Stress Defense (JAXA) • SpX-14: Metabolic Tracking	• Airway Monitoring – Lab Session (ESA) • Fluid Shifts • GRIP/GRASP (ESA) • SpX-15: Cell Science-02 • SpX-15: Rodent Research-7
JEM A/L Candidates	• NREP Mission 4 Transfer (TBD) • NRCSD #15 Deploy (OA-9) • MBSU IFM	
EVA, Robotics, Systems, Software	• SpX-14: PFCS Xfer, ASIM Install, MISSE Install • Linguini Service Pack • JSL 11.0 Software / Firewall Hardware Install • ESA MPCC 2.1 Software Transition • New USOS Printer Install / Checkout • USOS EVA: N3 EWC & CP8 R&R • USOS EVA: PFCS Relocate & CP13 R&R • USOS EVA: N2F EWC	• SpX-15: ECOSTRESS Install, LEE Xfer to ISS, HREP Dispose • Marinara Service Pack • JSL 11.1 Software Transition • USOS ITCS Gas Trap Plug Installation

Human Exploration and Operations

International Space Station:
FY 2018 and FY 2019 Operations and Maintenance Plans

- Operate Mission Control Center (MCC) 24/7 with primary responsibility for safety of crew and integrity of the ISS
- Operate Neutral Buoyancy Lab to conduct crew training and hardware development
- Perform cargo processing for six cargo missions in FY 2018 and six missions in FY 2019
- Provide on-orbit vehicle sustaining of both hardware and software
  - Nine on-orbit systems made up of 449 unique Orbital Replacement Unit Part Numbers
  - 52 main computers and 122 laptops in operations 24 hours a day / 7 days a week / 365 days a year
  - 24 computers control and operate core ISS, interface with International Partners, payloads, and visiting vehicles
- Plan and conduct ten U.S. Orbital Segment (USOS) EVAs in FY 2018 and at least seven USOS EVAs in FY 2019
- Sustain current fleet of Extravehicular Mobility Units (EMUs) plus perform life extension activities

Human Exploration and Operations

International Space Station:
FY 2018 and FY 2019 Operations and Maintenance Plans (continued)

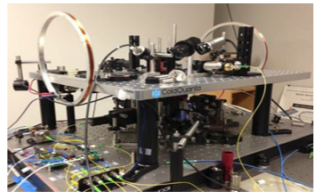
- Examples of other activities planned for FY 2018 – FY 2019
  - Complete Training Systems 21 modernization which will lower lifecycle costs
    - Previous contract was sole-sourced due to the uniqueness of the facility
    - Facility modernization allowed for a new competitive procurement of services, which should result in savings
  - Installation second and third Li-Ion Battery sets to replace Nickel Hydrogen batteries which are near end of life; launch batteries on H-II Transfer Vehicles (HTV)
  - Complete ISS Integrated Communications Unit (ICU) upgrade and interfacing flight and ground systems to achieve higher ISS Ku-Band return link payload data throughput
  - Develop and deliver ISS Water Storage System to reduce crew time needed to resupply water to the Regen ECLSS system
  - Continue development of Mini Pump Module to minimize USOS exposure to zero-fault tolerance by reducing recovery time for a pump failure to one EVA

Human Exploration and Operations

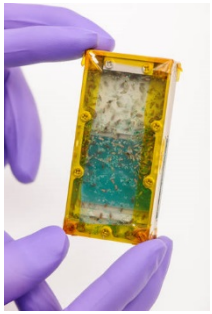
International Space Station Research: FY 2018 Plans

- Plans and examples of NASA BPS research on ISS
  - Complete Cold Atom Lab (CAL) experiment hardware, which will study Bose Einstein Condensates 100 picoKelvin above absolute zero
  - Conduct materials research in the Materials Science Research Rack using the Sample Cartridge Assembly for solidification of alloys in space
  - GeneLab Phase 3 Data system will go live increasing the ability of scientists to conduct data analysis and create next generation hypotheses about the effect of microgravity on plants, microbes, cells and rodents
  - Deliver Space Biology Pathfinder experiment on EM-1 through Life Beyond LEO science initiative
  - Conduct first science experiment in Advanced Plant Habitat using a multidisciplinary science team to apply advanced omics analysis to the study of plants in space
  - Enhance fruit Fly Lab 3 prior research by using multiple generations of fruit flies to provide further insight into immune system and cardiovascular research
  - Complete Advanced Colloids experiments using Light Microscopy Module to study underlying physics and behavior of complex fluids, commonly found in widespread commercial products such as paint, shampoos, and detergents

Advanced Plant Habitat



Cold Atom Laboratory

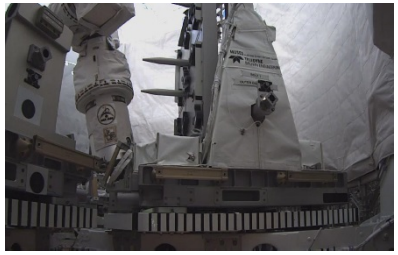


Habitat for the fruit fly

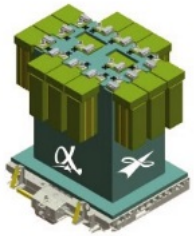
Human Exploration and Operations

International Space Station Research: FY 2018 Plans (continued)

- National Laboratory (CASIS) commercial research capabilities
  - Multiple User System for Earth Sensing (MUSES)
    - Developed by Deutsches Zentrum für Luft- und Raumfahrt (DLR) and Teledyne Brown Engineering, this hosts earth viewing instruments and a technology demonstration testbed
  - Mass Measurement Device
    - Developed by Orbitec, this device provides precise mass measurements in zero gravity; Will assist accuracy of experiments such as rodent research
  - BioChip Spacelab
    - Developed by Hnu Photonics, this modular locker facility provides an ultra-portable, remote-controlled, automated microfluidics platform for general biological investigations and planned stem cell research
  - Advanced Space Experiment Processor and the Multi-Purpose Variable Platform
    - Developed by Techshot, these can support multiple biological and material investigations in several compartments and adjustable gravity
  - Materials ISS Experiment Flight Facility (MISSE-FF)
    - Developed by Alpha Space Test and Research Alliance, this robotically serviceable permanent external platform enables passive and active materials investigations
- Examples of CASIS commercial investigations
  - Rodent Research-6 tests an implantable drug delivery system that circumvents the need for daily injections
  - Returned ZBLAN samples produced in microgravity to reduce imperfections - potential to replace silica-based fiber currently used in the internet and telecommunications industries



MUSES platform enables earth viewing and can be robotically serviced in flight

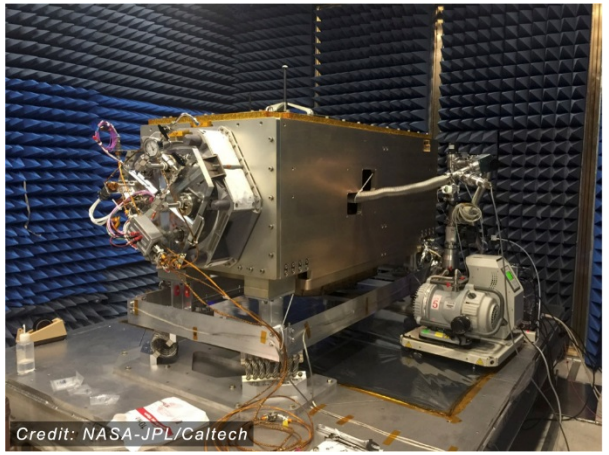


MISSE-FF platform will enable materials testing and data collection

Human Exploration and Operations

International Space Station Research: FY 2018 Plans (continued)

- NASA Science Mission Directorate research on ISS
  - Total and Spectral Solar Irradiance Sensor (TSIS)
    - Launched-SpX-13, on orbit
    - Provides measurements to support accurate scientific models of climate change and solar variability
  - Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)
    - Measure temperature of plants and looks to understand how much water plants need and how they respond to stress
    - Provides leading drought indicator, allowing time for decision-makers to take action
- New technology demonstration capabilities
  - Robotic Refueling Mission 3 technology demonstration to test in-space rocket propellant transfer technology
    - Could eventually help to diagnose satellite problems on orbit, fix anomalies, and keep spacecraft instruments performing longer in space

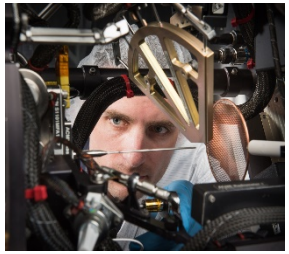


ECOSTRESS –EMI EMC test

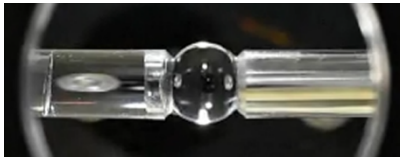
Human Exploration and Operations

International Space Station Research: FY 2019 Plans

- Plans and examples of NASA Biological and Physical Sciences (BPS) research on ISS
  - Continue study of gaseous fuel combustion processes with the Advanced Combustion Microgravity Experiment (ACME) in the Combustion Integrated Rack
    - Could help enhance fuel efficiency and reduce pollutant production in practical combustion on Earth.
  - Complete study of the transformation of protein solutions into amyloid fibrils, as happens in Alzheimer's patients, using Microgravity Science Glovebox
  - Identify biological countermeasures to stress in extreme environments through multigenerational spaceflight experiments on tardigrades (water-dwelling micro-animals) to help clarify molecular mechanisms employed by humans during stress tolerance
  - Determine effect of gravity on stem cells derived from a transgenic mouse differentiation, particularly as it relates to their osteoblasts cells used in osteoporosis research
  - Using microscopic worms, identify molecular changes that affect muscle strength in space with goal to identify genes that control muscle mass and strength
    - May ultimately help researchers design drugs to prevent muscle degeneration



ACME chamber insert



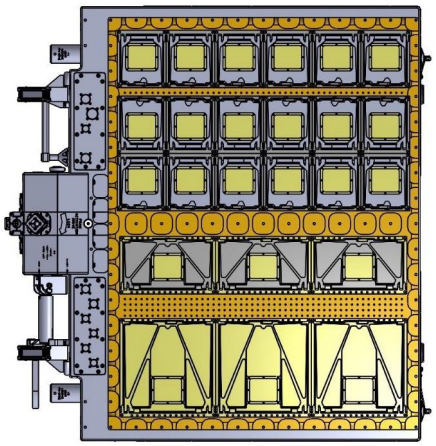
Studying fuel droplet in the high-speed rainbow schlieren deflectometry (RSD) apparatus which can operate at up to 2000 Hz

Photo of a tardigrade, which are also referred to as "water bears"

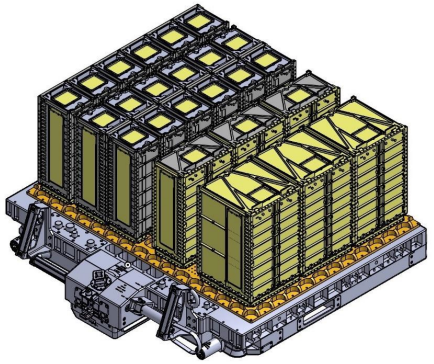
Human Exploration and Operations

International Space Station Research: FY 2019 Plans (continued)

- National Laboratory (CASIS) commercial research capabilities
  - bSpace ARQ
    - This external robotically serviced commercial platform hosts experiments and deploys small satellites and constellations
  - Remote Manipulator Small-Satellite System (RM3S)
    - Developed by LaMont Aerospace, this small satellite dispenser has capacity to deploy a large volume of nanosatellites within a single deployment cycle
  - BioFabrication Facility
    - Developed by Techshot, this provides advanced 3D printing technology of live cells producing vascularized tissues
- Examples of CASIS commercial investigations
  - Goodyear – evaluate novel silica morphologies to aid development of terrestrial manufacturing technologies - improve tire performance
  - Sanofi – study the effects of gravity on human immune function to develop better vaccines and immunobiologics for human use
    - Study lymphocyte (a type of white blood cell) functions in microgravity and explore whether age affects gravity-regulated immune pathways
  - AstraZeneca - study the effect of microgravity on the production of monoclonal antibodies (mAb), a type of therapeutic drug used to treat cancer and autoimmune diseases



RM3S: 6U, and 3 x 12U Dispensers (top view above)

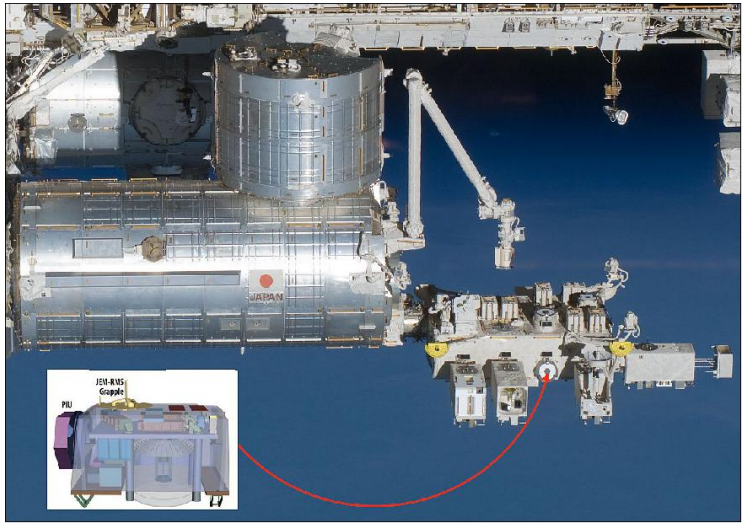


RM3S: 6U, and 3 x 12U Dispensers (side view)

Human Exploration and Operations

International Space Station Research: FY 2019 Plans (continued)

- NASA SMD research on ISS
  - Global Ecosystem Dynamics Investigation (GEDI)
    - First high resolution laser ranging observation of 3D structure of Earth
    - Multiple applications-weather forecasting, forest management, glacier monitoring, etc

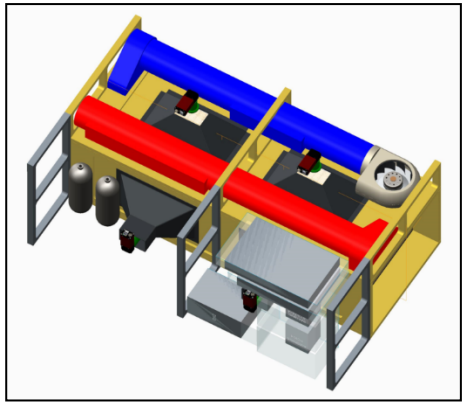


GEDI will be accommodated at the Japanese Experiment Module (JEM) -EF

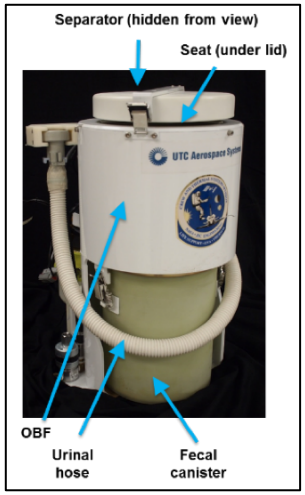
Human Exploration and Operations

International Space Station Research: FY 2019 Plans (continued)

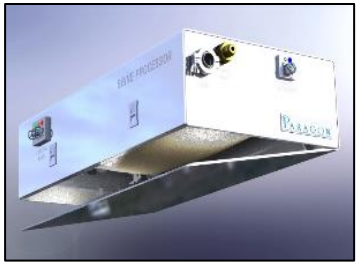
- New Technology Demonstrations on ISS to test the critical systems necessary for long-duration missions
  - Brine Processing Assembly (BPA) to improve to >90% recovery of water from Urine Brine
  - Universal Waste Management System (UWMS) provide improved metabolic waste management with fewer consumables
  - Siloxane control technology to eliminate contaminants that degrade ECLSS systems
  - Multifiltration (MF) beds Life Extension to provide water processing with reduced consumables
  - Long Duration In-Suit Waste Management for crew launch and entry systems (continuous duration of up to 144 hours)
  - Anomaly Gas Analyzer (AGA) on Spacecraft Fire Experiment (Saffire) - provide detection for hazardous combustion products, ammonia and hydrazine gases



Conceptual design of Saffire-IV-VI experiment module)
(Dimensions are approximately 53- by 90- by 133-cm)



Universal Waste Management System



Brine Processor Assembly

Human Exploration and Operations

International Space Station: Technology Development Activities

Capability Gap	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28
Environmental Control and Life Support											
Reliable CO2 Removal + ppCO2<2 mmHg					Expl system						
Trace contaminant sorbents/siloxane control					Expl system						
Regen particulate filtration/surface dust pre-filter											
Smaller, simpler O2 Gen		OGA Upgrades									
High pressure O2 (3000 psi) for EVA & medical use				HP OGA or concentrator							
Reliable urine processing =85% recovery	DA mods										
Reliable H2O processing w/ reduced expendables	IF life ext			CR mod							
Compact waste & trash mngmt, stable, 90% water recov	UWMS				HMC						
Additional O2 recovery from CO2 >75%				PPA			alt tech				
>90% recovery of water from urine brine		BPA									
Condensing HX robust, inert, anti-microbial				flt demo							
Environmental Monitoring, Safety and Emergency Response											
Trace Gas (on orbit, no grab sample return)		SAM									
Targeted Gases (fire products, NH3, hydrazine)		AGA on saffire									
Water (individual compounds)			final flt suite								
Microbial (ID & qty species)			Expl PCR								
Major Constitutents (small, no maintenance)		SAM/MPAM									
Particulates				flight monitor							
Acoustic (automated, alerting, no crew time)		Combination acoustic monitor									
Emergency Mask (single cartridge)				single; sorbent demo on Saffire IV-VI							
Contingency Air Monitor (overlap with targeted gas)				Demo in Saffire IV-VI							
Smoke Eater				Demo in Saffire IV-VI							
Water Mist PFE				Expl. Size, lightwt tank for Orion							
Large fire behavior in ug				Saffire-IV-VI							
Extravehicular Activity											
Exploration Extravehicular Mobility Unit (xEMU)									ISS demo		
Long Duration In-Suit Waste Management											
Active Thermal Management for xEMU		SERFE									
Human Health & Performance											
Exercise Equipment				ATLAS							
Medical Equipment	*(ground testing only - no flight tests currently planned)*										
Food System					Adv food system						
Radiation											
Radiation Monitoring	FNS										
Communications, Navigation, and Networking											
High speed comm/internetworking				LLUMA-T		TDRS Ka-band upgrades					
Position, navigation, and timing	NICER/SEXTANT										
Materials, Manufacturing, Sustainability, and Supportability											
10:1 volume reduction logistical & clothing	REALM				simple laundry						
ISM Recycling & Fabrication		ERASMUS (Medical, Food Grade Recyling)									
ISM FabLab Demo (Metals, Electronics, etc.)					Flight Demo						
Avionics, Software and Autonomy											
Augmented Reality	T2 AR										
Automated Mission Operations	AMO Express 2.5										
Other Phase 0 demonstrations											
Zero Boil Off Cryo											
Structures & Health Monitoring	BEAM										

▲ ISS demo - flying
▲ ISS demo - in development
△ Proposed ISS demo

Commercial LEO Development Program

Human Exploration and Operations

Commercial LEO Development: Overview

- Stimulate a commercial LEO space economy by supporting U.S. private industry to encourage development of LEO capabilities that can be used by NASA, international, and commercial customers
  - NASA would rely on commercial partners for its low Earth orbit research and technology demonstration requirements after ending direct U.S. financial support for ISS in 2025
- Focus on enabling, developing, and deploying commercial platforms and other capabilities
- There are options available that would achieve the vision of a commercial LEO economy where NASA is one of many customers
  - NASA plans to task commercial industry to submit formal proposals, including market analysis and business plans, for these options
- Objective is for there to be a seamless transition to this new operating paradigm

Human Exploration and Operations

Commercial LEO Development: Commercialization LEO Plan

Vision: Sustained U.S. commercial LEO human space flight marketplace where NASA is one of many customers

Policy and regulatory environment

- Support Space Council in whole-of-government approach for commercial space
- Facilitate multi-agency research decadal plan and support for LEO research
- Understand and address marketplace needs
- Execute plan for ISS transition to provide transparency and certainty for the marketplace
- Implement new ISS commercial use policy

Self-sustaining supply of U.S. commercial services to/in/from LEO accommodates public and private demand

- Enable cost effective commercial crew and cargo transportation
- Enable ISS commercial facilities and capabilities that can transition to commercial platforms
- Facilitate new commercial LEO platforms and services and transition to NASA-as-customer

Demand from broad sectors of the economy for LEO activities

- Maximize value and impact of the NASA resources
- Communicate value of LEO and foster “success stories”
- Communicate forecast for ongoing NASA demand for LEO utilization

Human Exploration and Operations

Commercial LEO Development: FY 2018 – FY 2019 Plans

- FY 2018 Plans
  - Announce an open competition for commercial module(s)/platform(s) attached to ISS or free-flying in LEO, and other capabilities, which would be partially or fully funded by private industry
    - Utilize module/platform for commercial, for-profit activities beyond NASA's and the National Lab's missions
    - Allow private industry to experiment with commercial activities and demonstrate the viability of commercial LEO activities
- FY 2019 Plans
  - Make award(s) for commercial module(s)/platform(s)/capabilities
  - Make available specific ISS accommodations for resources such as power, thermal control, habitable atmosphere, and other common ISS services and capabilities

Space Transportation

Crew and Cargo Program
Commercial Crew Program

Human Exploration and Operations

Crew and Cargo Program: Overview

- Provide cargo resupply services from U.S. private sector companies
  - CRS-1: Orbital ATK and SpaceX
  - CRS-2: Orbital ATK, Sierra Nevada, and SpaceX (flights beginning in FY 2020)
- Provide crew transportation to ISS
  - Soyuz seats through launch in spring 2019
  - First commercial crew Post Certification Mission planned for April 2019
    - Total of two Post Certification Missions are funded by Commercial Crew Program; remaining missions are funded by Crew and Cargo Program
- Provide other support related to crew and cargo transportation to ISS
  - Related support includes visiting vehicle integration, civil servant labor and travel, and other activities such as the NASA Docking System

Human Exploration and Operations

Crew and Cargo Program: Commercial Resupply Status

- Orbital ATK
  - Completed demonstration flight on October 22, 2013; completed seven CRS missions
    - Orb-1 February 18, 2014
    - Orb-2 August 15, 2014
    - Orb-3 October 28, 2014 (anomaly)
    - OA-4 December 6, 2015
    - OA-6 March 22, 2016
    - OA-5 October 17, 2016
    - OA-7 April 18, 2017
    - OA-8 November 12, 2017
  - Five missions currently in flow (OA-9 through OA-13)
    - OA-12 and OA-13 are CRS-2 missions
  - Completed initial CRS-2 integration milestones
  - NASA paid $2.8B through the end of December 2017
  - Launches from Mid-Atlantic Regional Spaceport at Wallops Flight Facility in Virginia
- Sierra Nevada
  - One CRS-2 mission currently in flow (SNC-1)
  - Completed initial CRS-2 integration milestones
  - NASA paid $136M through the end of December 2017
  - Will launch from Cape Canaveral Air Force Station (CCAFS)

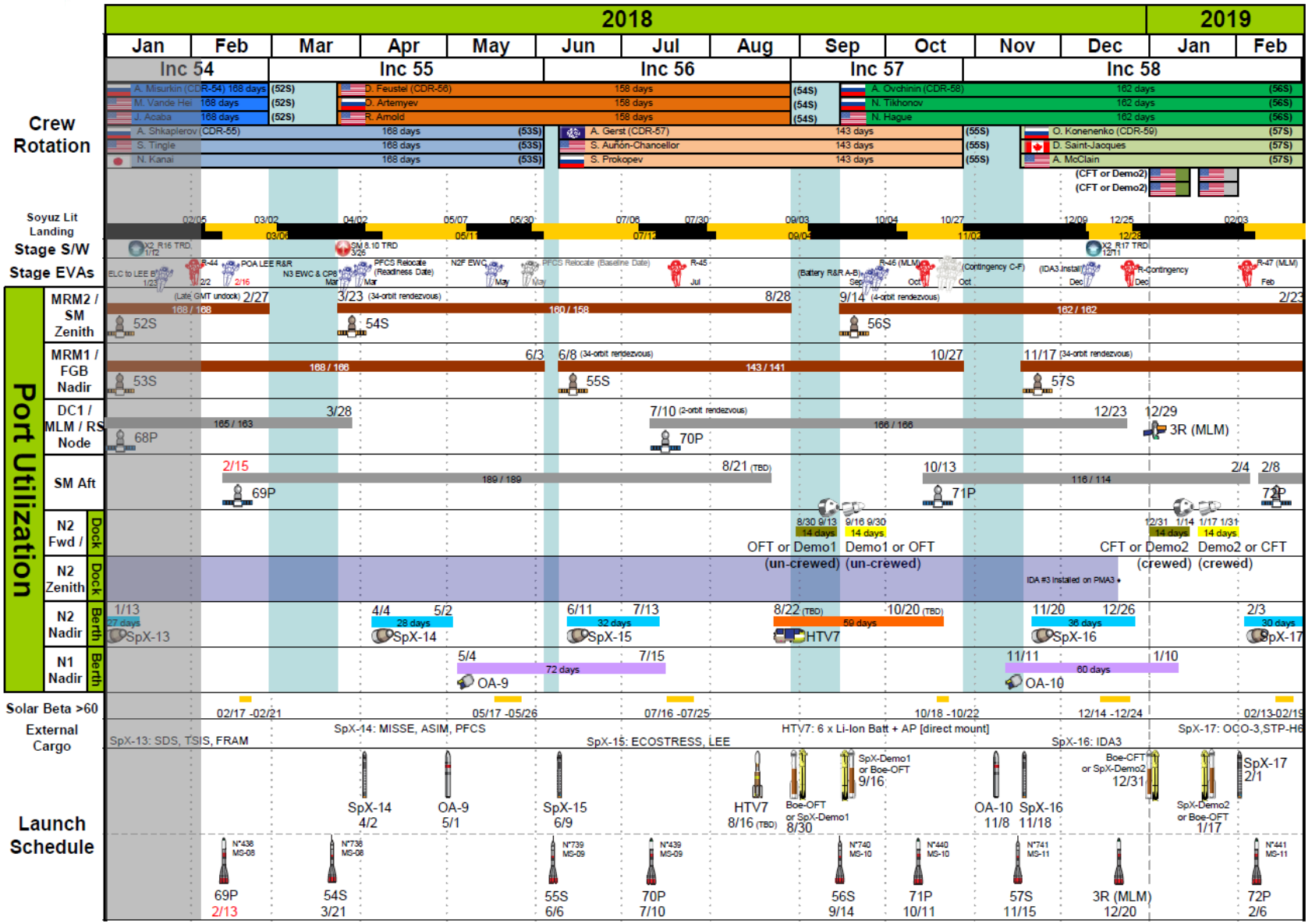
Human Exploration and Operations

Crew and Cargo Program: Commercial Resupply Status

- Space Exploration Technologies Corporation (SpaceX)
  - Completed demonstration flight - May 31, 2012; completed twelve CRS missions:
    - SpX-1 October 28, 2012
    - SpX-2 March 27, 2013
    - SpX-3 May 18, 2014
    - SpX-4 October 25, 2014
    - SpX-5 February 10, 2015
    - SpX-6 May 21, 2015
    - SpX-7 (anomaly)
    - SpX-8 April 8, 2016
    - SpX-9 July 18, 2016
    - SpX-10 February 19, 2017
    - SpX-11 June 3, 2017
    - SpX-12 August 14, 2017
    - SpX-13 December 15, 2017
  - Nine missions currently in flow (SpX-14 through SpX-22)
    - SpX-21 and SpX-22 are CRS-2 missions
  - Completed initial CRS-2 integration milestones
  - NASA paid $2.7B through the end of December 2017
  - All launches at Cape Canaveral, Florida

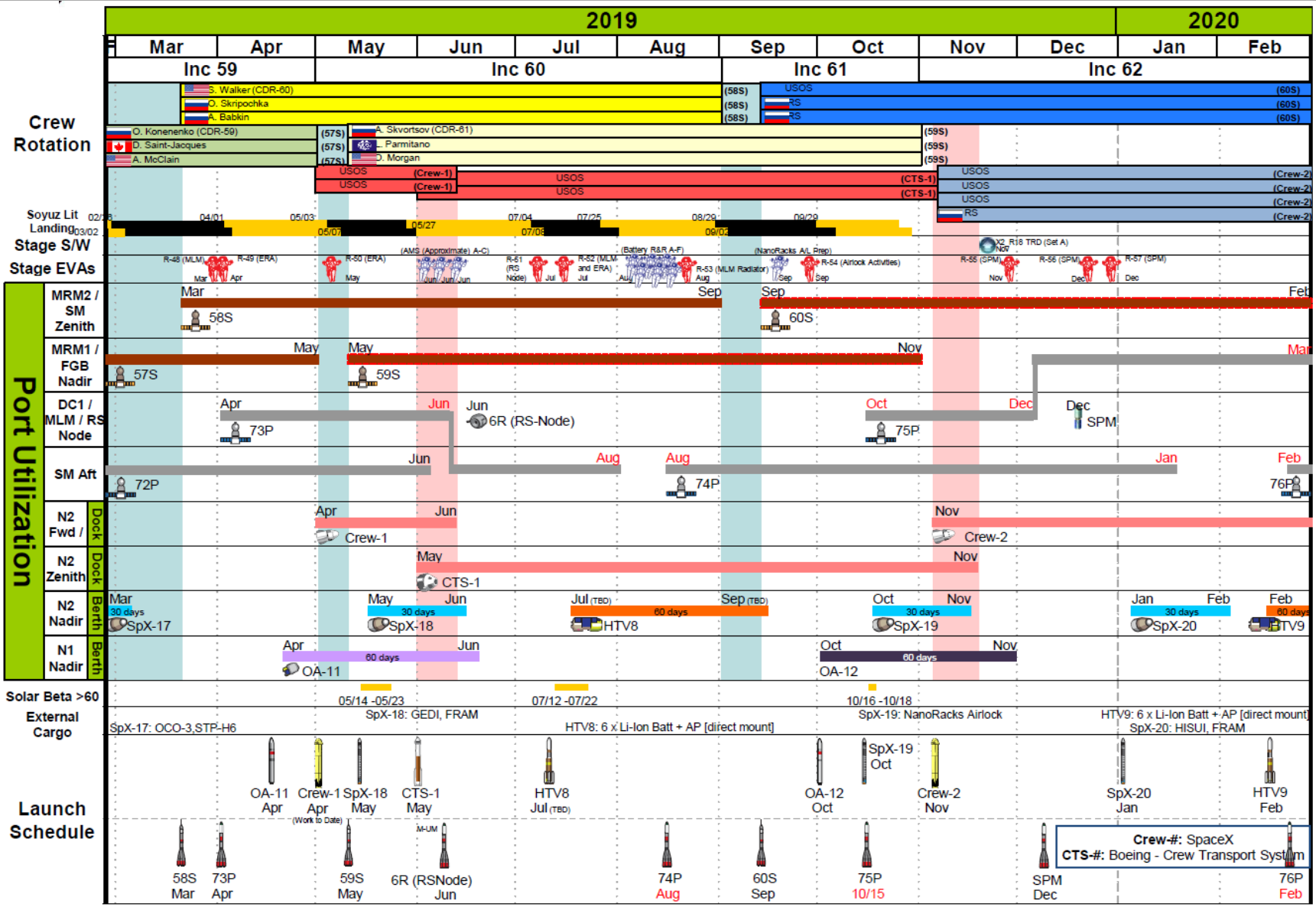
Human Exploration and Operations

Crew and Cargo Program: Schedule/Milestones (draft as of 2/15/18)



Human Exploration and Operations

Crew and Cargo Program: Schedule/Milestones (draft as of 2/15/18)



Human Exploration and Operations

Crew and Cargo Program: FY 2018 – FY 2019 Plans

- FY 2018 Plans
  - Launch five CRS missions: OA-8, OA-9, SpX-13, SpX-14, and SpX-15
  - Launch crew transportation purchased from Russia for six astronauts via Soyuz
  - Launch additional Soyuz increment from Boeing
  - Dock commercial crew demonstration missions to ISS (uncrewed)
- FY 2019 Plans
  - Launch five CRS missions: OA-10, OA-11, SpX-16, SpX-17, and SpX-18
  - Launch crew transportation purchased from Boeing for three astronauts via Soyuz
  - Dock commercial crew demonstration missions to ISS (crewed)
  - Receive first commercial crew Post Certification Mission to ISS

Human Exploration and Operations

Commercial Crew Program: Overview

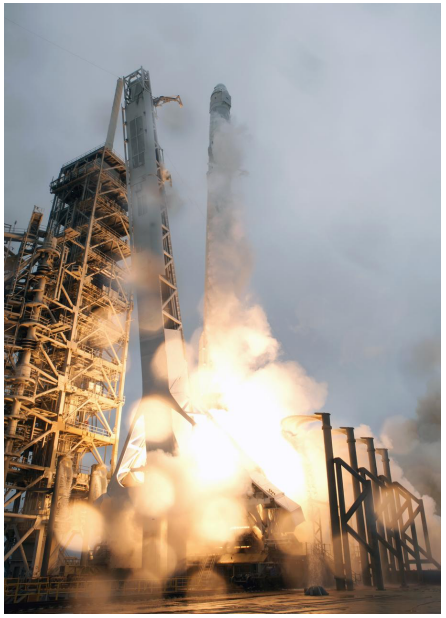
- Facilitate development of U.S. commercial crew space transportation capability and certify partner vehicles by 2019
- Achieve safe, reliable, and affordable crew access to and from LEO, including ISS
- In September 2014, awarded Commercial Crew transportation Capabilities (CCtCap) contracts to SpaceX ($2.6B) and Boeing ($4.3B) (maximum potential contract value)
  - Utilized competition to maximize safety and control long-term costs
  - Evaluate development results to ensure NASA safety and performance requirements met
  - Total of two Post Certification Missions funded by Commercial Crew Program; remaining Post Certification Missions funded by Crew and Cargo Program
    - Total of six Post Certification Missions awarded to each partner

Human Exploration and Operations

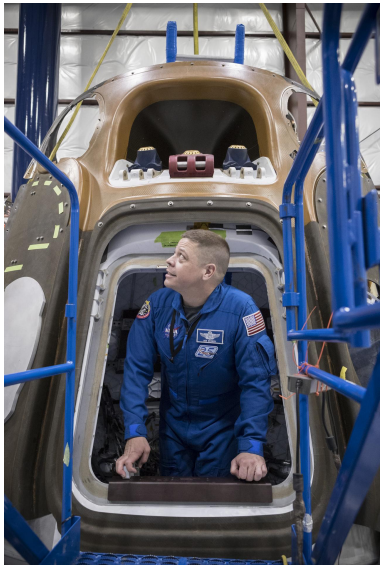
Commercial Crew Program: SpaceX Approach

SpaceX Crew Dragon

- SpaceX Crew Dragon transportation system capsule uses SpaceX Falcon 9 launch vehicle and lands using parachutes for water landing
- Commercial Crew missions launch from Kennedy Space Center (KSC) in Florida; pad modifications in progress



Inaugural Falcon 9 launch from Pad 39A

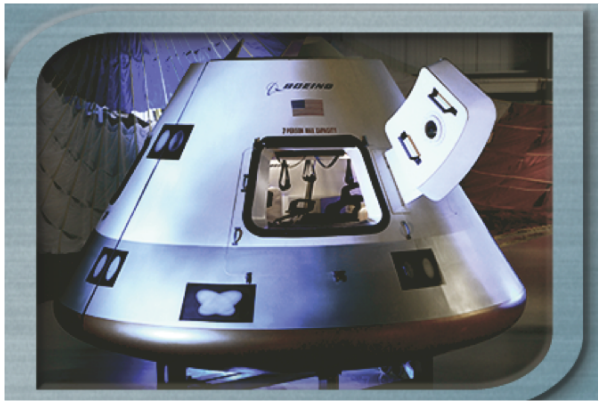


NASA crew egresses from Dragon Spacecraft

Personnel from NASA, SpaceX, and the U.S. Air Force practice astronaut recovery operations for the Dragon Spacecraft

Human Exploration and Operations

Commercial Crew Program: Boeing Approach



Boeing Starliner

- Boeing Starliner crew transportation system capsule uses United Launch Alliance Atlas 5 launch vehicle; lands using parachute and airbag systems for hard surface or contingency water landings
- Vehicles launch from Cape Canaveral Air Force Station (CCAFS)

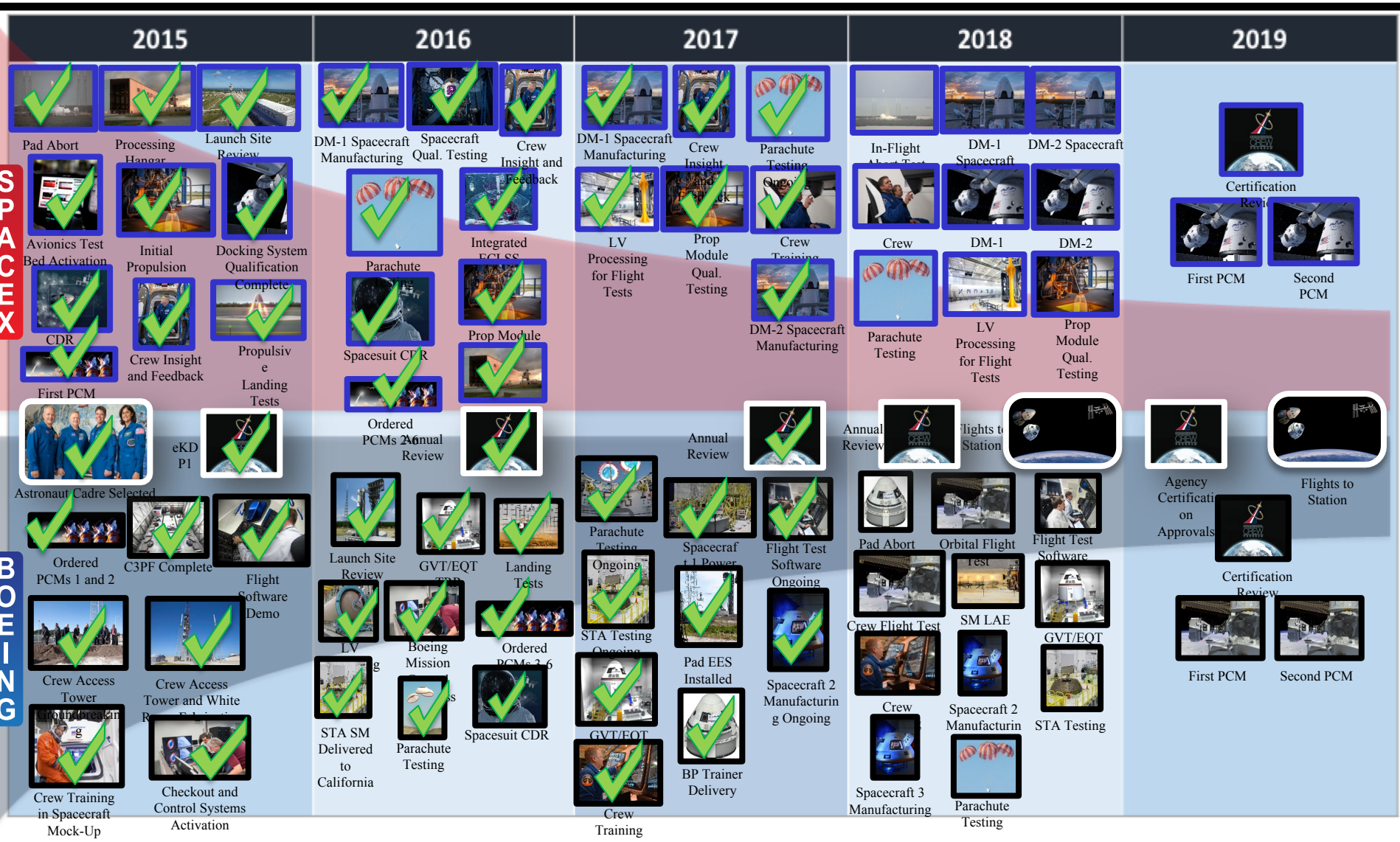
Structural test article completed in the company's facility at NASA's Kennedy Space Center

Spacecraft launch abort engine test

Spacecraft land landing qualification tests

Human Exploration and Operations

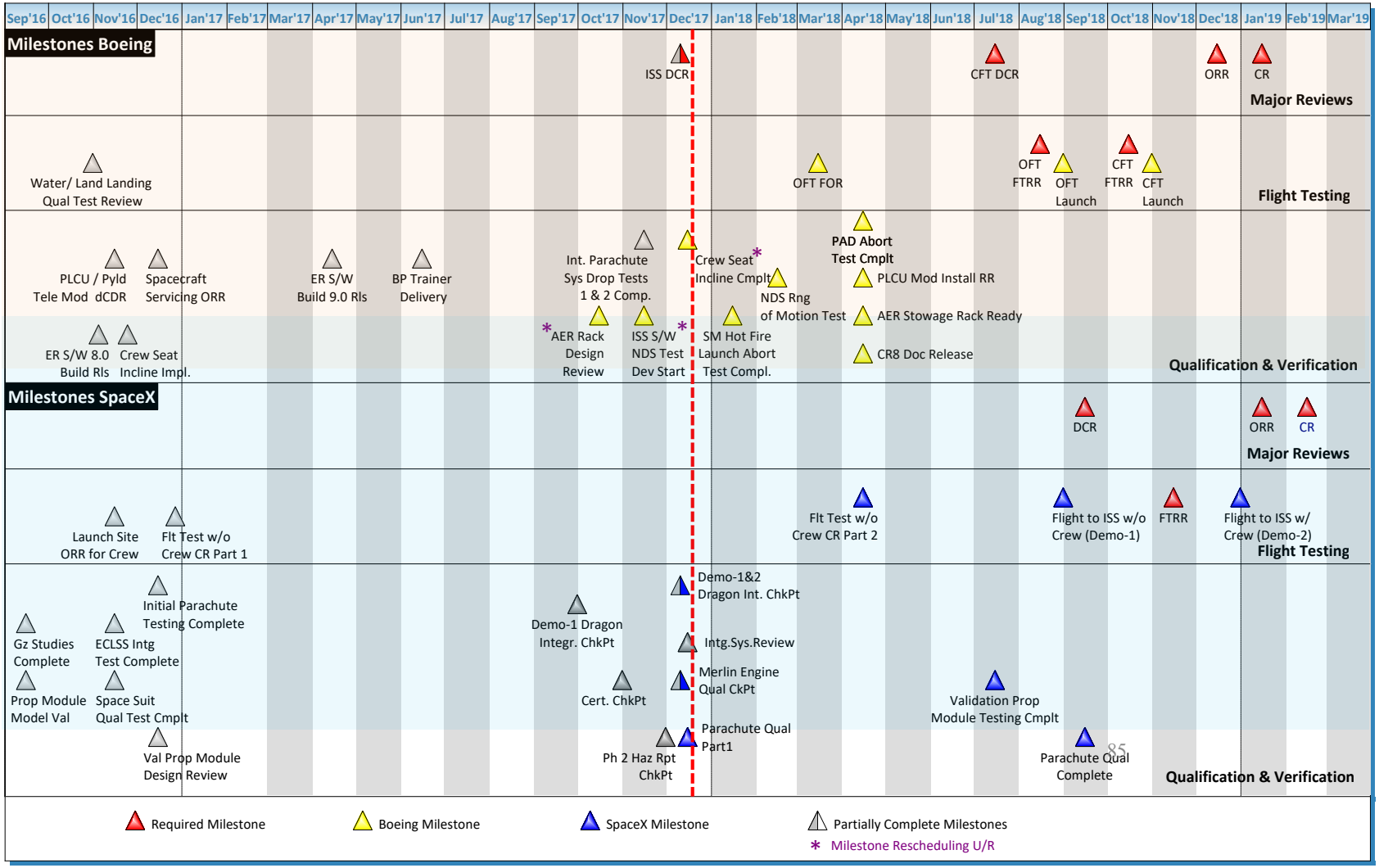
Commercial Crew Program:
Transportation to the International Space Station



Last Updated January 2018

Human Exploration and Operations

Commercial Crew Program:
CCtCap Combined Milestone Summary



SBU: Company Proprietary and NASA Sensitive Data

CCtCap CMS - Dec 18,2017
Data Source: Boeing FY17Q4 / SpaceX FY17Q4
POC: Deborah Cole, 321-867-0834

Human Exploration and Operations

Commercial Crew Program: FY 2018 Plans

- Through FY 2018, Boeing plans to complete 36 of 39 milestones, including a major review milestone, ISS Design Certification Review, Pad Abort Test, and Orbital Flight Test (not a milestone)
  - Boeing will continue with production and outfitting three crew modules and multiple service modules
  - Boeing's spacesuit will undergo integrated system verification tests, including environmental control and life support system (ECLSS) testing
- Through FY 2018, SpaceX plans to complete 21 out of 25 milestones, including a Design Certification Review and Flight Test without crew
  - SpaceX will continue forward work on their six spacecraft crew modules and ongoing qualification and validation testing on its advanced spacesuits, including suit-fit and pressure tests
- Sierra Nevada Corporation completed their final funded milestone, Engineering Test Article (ETA) Flight Testing, in early FY 2018 under Commercial Crew integrated Capability Space Act Agreement, or CCiCap

Human Exploration and Operations

Commercial Crew Program: FY 2019 Plans

- SpaceX is scheduled to complete its final CCiCap milestone, In-flight Abort Test
- Partners will continue to mature capabilities toward securing U.S. crew transportation capability to ISS by 2019
  - Boeing and SpaceX are planning to complete all development milestones, including milestones supporting their crewed demonstration missions and Certification Reviews
  - Boeing is on contract to complete certification by January 2019; begin PCM flights in May 2019
  - SpaceX is on contract to complete certification by February 2019; begin PCM flights in April 2019

Space Flight Support

Space Communications and Navigation
Rocket Propulsion Testing Program
Launch Services Program
Human Space Flight Operations

Human Exploration and Operations

Space Communications and Navigation: Overview

- Provide assured critical communication coverage from near Earth and through the edge of the solar system to enable all NASA and partners science and human exploration missions well into the 21st century (Space, Near Earth, and Deep Space Networks)
  - Continue > 99% service proficiency for all networks
  - Continue enhancements and modernization efforts
- Invest in future network capabilities to develop future space-based relay communication and navigation architectures for Earth and Mars
  - Pursue potential public-private partnerships to further commercialization of LEO
  - Lead interoperability with national, international and commercial partnerships
- Lead communications technology development while leveraging partnerships
  - Demonstrate optical communication capability for both deep space and near Earth missions
  - Transition optical communication technology from demonstration to operations
- Lead, represent and negotiate on behalf of NASA nationally and internationally to protect spectrum, develop positioning, navigation and timing policy and enable interoperable architectures
- Support the development and initial piloting of a strategy to transition the Space Network to a mix of commercial services, where available, and public-private partnerships (where new technologies are needed)

Human Exploration and Operations

Space Communications and Navigation: Networks

SCaN networks provide support to NASA and other missions with facilities located around the world. Deep Space Network (DSN) supports mainly interplanetary missions, Near Earth Network primarily polar earth resources missions, and Space Network a combination of Earth science, space science, support to ISS and other government customers

Human Exploration and Operations

Space Communications and Navigation: FY 2018 Plans

- Continue sustainment activities for the Space Network
  - Completed on-orbit acceptance of TDRS-M
  - Started integration and testing of SGSS at White Sands Complex
  - Complete Independent Review of SGSS
- Continue Near Earth Network upgrades
  - Begin Ka-Band upgrades at Alaska Satellite Facility
- Continue Deep Space Network upgrades
  - Complete pedestal construction for Deep Space Station (DSS)-56 and DSS-53 and continue antenna fabrication
  - Begin requirements study for DSN Aperture Enhancement Project (DAEP) to convert DSS 23/33 to hybrid optical
  - Successfully implement DSN Follow-the-Sun operations at all three complexes
- Continue technology development and partnerships to evolve critical future exploration capabilities, such as optical communications
- Engage commercial industry to complete Pre-Phase A studies for Next Generation Earth Relay satellite

TDRS-M launch August 18, 2017 and completed on-board acceptance review in FY 2018 Q2

DSS-56 Pedestal Construction

Human Exploration and Operations

Space Communications and Navigation: FY 2019 Plans

- Continue Space Network upgrades
  - Given the budgetary challenges encountered by the project, the FY 2019 Budget does not provide funding for the continuation of SGSS. A final decision on SGSS continuation will be deferred until the conclusion of the independent review
  - If results of the Independent Review point towards an affordable path forward for SGSS, NASA will look for opportunities to continue SGSS and achieve 1st ORR in FY 2019
- Continue Near Earth Network upgrades
  - Continue Ka-Band upgrades at Alaska Satellite Facility
- Continue Deep Space Network upgrades
  - Complete antenna fabrication for DSS-56 and DSS-53; begin installation, integration and test activities
  - Continue requirements study and begin implementation for DAEP to convert DSS 23/33 to hybrid optical
- Continue technology development and partnerships to evolve critical future exploration capabilities, such as optical and quantum communications
- Begin development and implementation of optical payloads for Next Generation Earth Relay and identify potential participation from commercial industry and other government agencies

Human Exploration and Operations

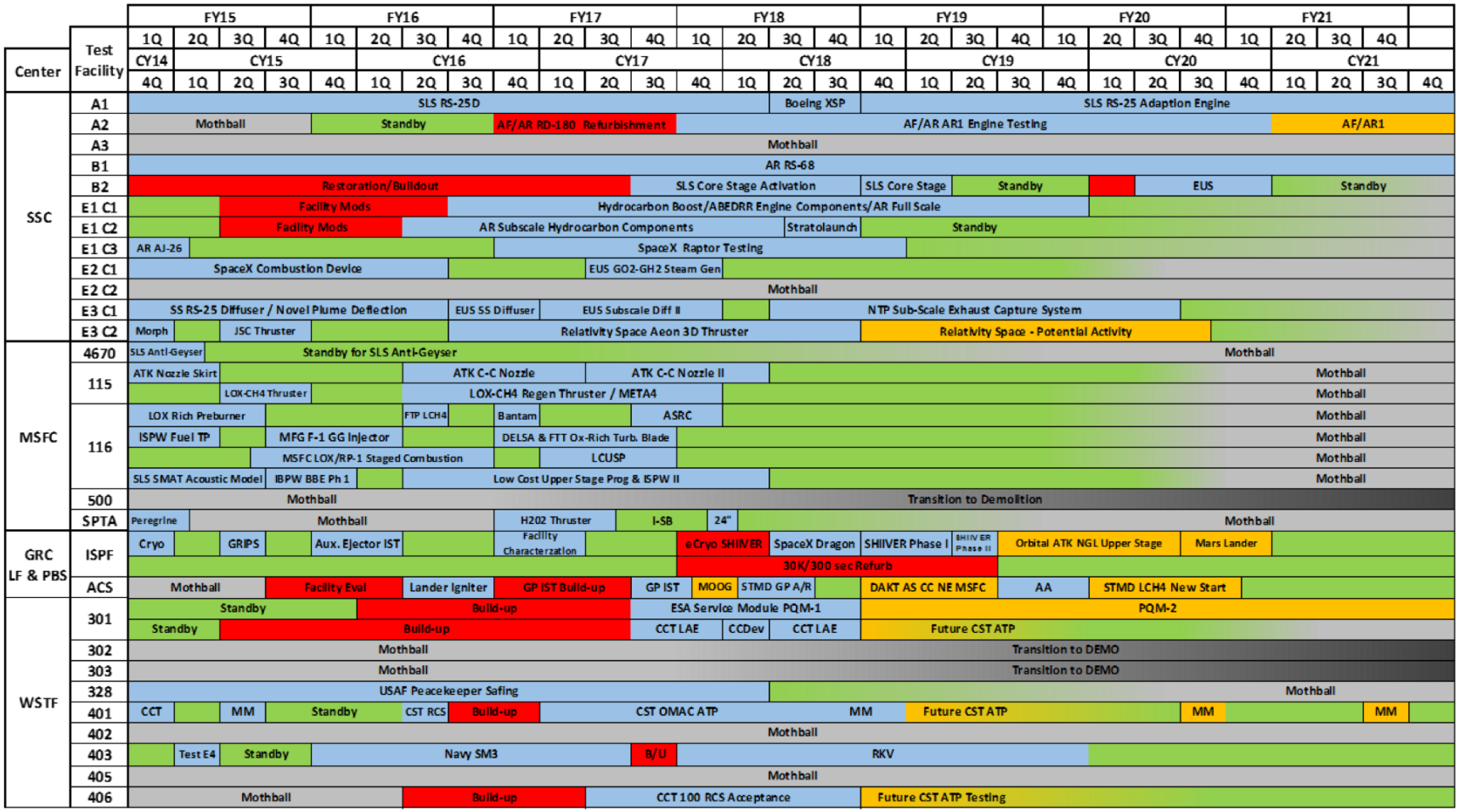
Rocket Propulsion Testing: Overview

- Fund and maintain prioritized core capability of skilled test and engineering crews, and test stand facilities
- Enable propulsion test infrastructure for NASA programs, commercial partners, and Department of Defense (DoD)
- Coordinate and integrate multi-site test activities to reduce propulsion test costs
  - Maintain assets to meet current and future test requirements
  - Approve and provide direction on test assignments
  - Provide a single entry point for any user of the rocket test stands
  - Support prioritized facility maintenance and modernization projects according to utilization requirements
- Represent the Agency on the National Rocket Propulsion Test Alliance
  - Expand cooperation between NASA and DoD
  - Facilitate effective use of all U.S. Government's rocket propulsion test capability

RPT continues to support SLS RS-25 engine testing on the A-1 test stand at Stennis Space Center in Mississippi

Human Exploration and Operations

Rocket Propulsion Testing: Schedule/Milestones



As of 01/26/18

Mothball | Committed | Refurb/Build-up | Inactive Standby | High Probability

The RPT Management Philosophy Is To Continuously Monitor And Adjust Facility Readiness Based On Current And Future Agency Needs.

Although History Has Shown Smaller Test Programs Often Have Short Build-Up, Test Campaigns, And Notification, This Utilization Schedule Reflects Gradual Transitions To Mothball State For Facilities Based On Currently Known Requirements.

Human Exploration and Operations

Rocket Propulsion Testing: FY 2018 Plans

- RPT Program Office
  - Develop two small test capabilities
    - Small 5K pounds of force portable test rig
    - Larger 10K-15K pounds of force portable test rig, to be designed and developed by early career engineers
  - Undergo benchmarking effort of U.S. (government or commercial) test sites to improve efficiencies and affordability at all RPT centers
- Stennis Space Center
  - Provide propulsion test data to SLS and Orion as they prepare for EM-1 and EM-2
  - Continue hot fire testing the SLS RS-25 engine on A-1 test stand
  - Continue Aerojet Rocketdyne RS-68 engine certification
  - Refurbish and repair critical enabling infrastructure
    - Repair SSC's liquid oxygen and liquid hydrogen barges
    - Replace E-Complex data acquisition system and high speed video equipment
    - Activate B-2 test stand to prepare for SLS core stage testing
  - Perform testing for U.S. Air Force designed and developed Hydrocarbon Boost components that support future ISS resupply requirements Complete construction of joint Michoud Assembly Facility/SSC consolidated Fluid Component Processing Facility (FCPF)
  - Continue relationship with commercial partners, Space X and Relativity Space, to test engine and engine components on the E-1 and E-3 test stands

Human Exploration and Operations

Rocket Propulsion Testing: FY 2018 Plans (continued)

- Glenn Research Center Plum Brook Station
  - Provide propulsion test data to SLS, Orion, and commercial customers
  - Continue improvements to future space exploration propulsion needs through the Evolvable Cryogenics Project-eCRYO
  - Support research to reduce the boil-off rate on large cryogenic upper stages with the Structural Heat Intercept, Insulation and Vibration Evaluation Rig (SHIVER) in a simulated space environment (vacuum and thermal)
  - Perform critical environmental testing for the SpaceX Dragon Crew Capsule
  - Initiate 30k-lb/300 seconds refurbishment activities supporting future in-space and lander test requirements
- White Sands Test Facility
  - Complete ESA Service Module and Boeing Starliner Service Module integrated testing
  - Perform acceptance testing on all Boeing Starliner Service Module thrusters
  - Continue propulsion system development and certification testing for the Missile Defense Agency, U.S. Air Force, and U.S. Navy
- Marshall Space Flight Center
  - Continue testing rocket engine components constructed using select laser melting and other additive manufacturing processes

Human Exploration and Operations

Rocket Propulsion Testing: FY 2019 Plans

- Stennis Space Center
  - Continue to provide propulsion test data to SLS and Orion as they prepare for EM-1 and EM-2
  - Continue hot fire testing SLS RS-25 engine on A-1 test stand
  - Prepare the newly refurbished B-2 test stand for the SLS Core Stage on the newly refurbished B-2 test stand
    - The core stage uses four RS-25 engines to propel the SLS during launch
- Glenn Research Center Plum Brook Station
  - Complete 30k/300 seconds refurbishment activities supporting future in-space and lander test requirements
  - Provide data to SLS by completing the eCRYO project
  - Perform critical environmental testing for SpaceX Dragon Crew Capsule
- White Sands Test Facility
  - Continue testing activities for Orion ESA Service Module and Boeing Starliner Service Module
  - Provide critical propulsion test services to Missile Defense Agency, Aerojet Rocketdyne and USAF test articles

Human Exploration and Operations

Launch Services Program: Overview

- Provides management of NASA Launch Services contracts, launch mission assurance, and mission design and launch integration support
- Enables NASA Administrator to execute role as launch agent for U.S. civil sector, as described in National Space Transportation Policy
- Certifies new commercial launch vehicles for readiness to fly NASA spacecraft
- Conducts engineering analyses and other technical tasks that maximize launch success for every NASA science payload and communication satellite
- Provides launch related expertise to other government agencies and launch industry to ensure launch opportunities are available on a range of systems


Pegasus XL


Atlas V


Delta II

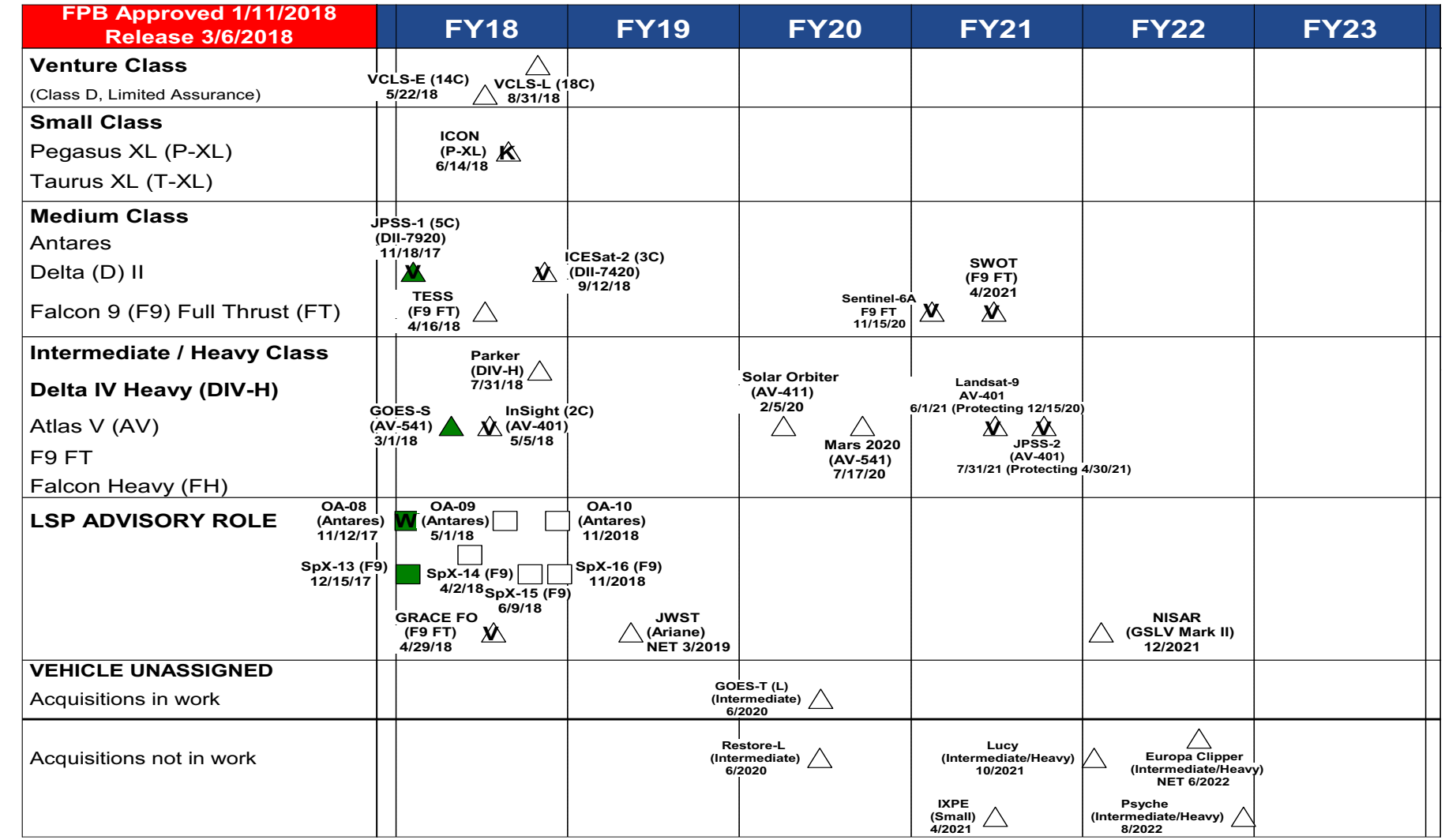
Antares 230

Falcon 9


Delta IV Heavy

Human Exploration and Operations

Launch Services Program: Schedule/Milestones



Human Exploration and Operations

Launch Services Program: FY 2018 – 2019 Plans

- Provide mission design and launch integration support to over 40 missions in various stages of development
- Launched Joint Polar Satellite System (JPSS) 1, on November 10, 2017
- Successfully launch
  - Geostationary Operational Environmental Satellites (GOES)-S, scheduled for March 2018
  - Transiting Exoplanet survey Satellite (TESS), scheduled for March 2018
  - Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), scheduled for May 2018
  - Ionospheric Connection Explorer (ICON), scheduled for June 2018 (U/R)
  - Parker Solar Probe (formerly Solar Probe Plus), scheduled for July 2018
  - Ice, Clouds, and Land Elevation Satellite (ICESat-2), scheduled for September 2018
- Develop plan for commercial logistics services for Lunar Orbital Platform-Gateway
- Certify new commercial launch vehicles to launch high value civil sector payloads
- Provide launch related advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP
- Conduct and manage Venture Class Launch Service contracts for emerging small-class launch vehicles (e.g., Virgin Galactic's "Launcher One" and Rocket Lab USA's "Electron")

Human Exploration and Operations

Human Space Flight Operations: Overview

- Space Flight Crew Operations
  - Provide trained astronauts for all NASA human space flight efforts
    - Direct and manage flight crew activities
    - Select astronaut candidates for future space flight missions
    - Provide human space flight operational support to programs and advisory boards
    - Provide design review advisory support to CCP and Orion Program
  - Operate program support aircraft for space flight readiness training and direct crew return
- Crew Health and Safety
  - Maintain Astronaut Occupational Health program
    - Clinical care, psychological care, certification for active astronauts,
    - Medical support during astronaut training
    - Lifetime surveillance program to identify long term or latent crew health concerns resulting from preparations for flight and exposure to space environments
  - Provide subject matter expertise and data analytics support to monitor and mitigate highest human health and performance risks to NASA spaceflight crews

Human Exploration and Operations

Human Space Flight Operations: FY 2018 – FY 2019 Plans

- Space Flight Crew Operations
  - FY 2018 Plans
    - Provide training requirements and mission operations support for first commercial test flights of NASA crewed SpaceX Dragon and Boeing Starliner commercial spacecraft
    - Continue training new Astronaut Candidate (ASCAN) Class of 2017
    - Support ISS flight crew training requirements and ISS mission operations
      - Russian Soyuz spacecraft launch vehicle
      - U.S. commercial spacecraft (SpaceX Dragon and Boeing Starliner) launch vehicles
      - Increase in crew size on ISS from six to seven
  - FY 2019 Plans
    - Complete FY 2017 ASCAN training
    - Decide on need for a FY 2020 ASCA class
    - Operate program support aircraft
    - Continue support to ISS flight crew training requirements and ISS mission operations

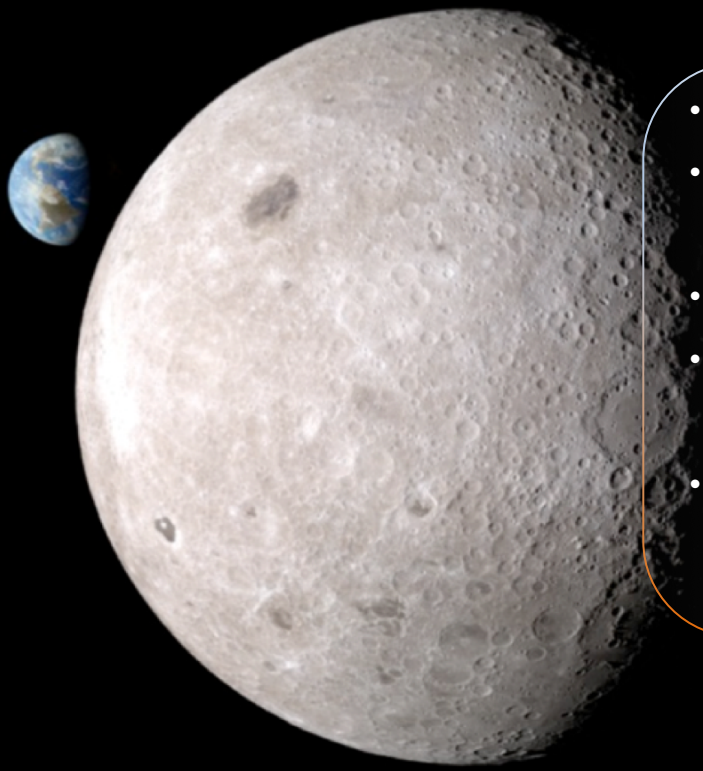
Astronaut Candidate Class of 2017

Human Exploration and Operations

Human Space Flight Operations: FY 2018 – FY 2019 Plans

- Crew Health and Safety
  - Implement "To Research, Evaluate, Assess, and Treat" Astronauts (TREAT) Act to include expanding Lifetime Surveillance of Astronaut Health program for former crew members to better understand long-term health consequences of space exploration
  - Expand data analytics capabilities to support medical diagnostic capabilities for exploration missions including gateway missions
  - Provide pre-flight through post flight medical, behavioral and physical conditioning support of NASA SpaceX Dragon and Boeing Starliner commercial spacecraft crew
  - Provide test personnel and medical guidance in support of EM-2
  - Meet pre-flight training, medical, behavioral health management, physical conditioning and baseline occupational surveillance requirements in support of ISS increments crew
  - Support in-flight medical and behavioral health management operations, implement onboard physical conditioning and in-flight occupational surveillance requirements to crew during ISS increments
  - Provide post-flight clinical, behavioral and reconditioning services to NASA crew members returning to Earth from ISS increments

HOW ARE WE LEADING FUTURE EXPLORATION



- Building a platform that will orbit the Moon
- Sending landers to the lunar surface in preparation for a human return
- Stimulating the low-Earth orbit commercial space economy
- Developing technologies needed for exploration and resolving human health and performance challenges
- Expanding US leadership through partnerships with commercial industry and other nations

Back-up

Human Exploration and Operations

Acronym List

AA	Ascent aborts
ACSC	Advanced Cislunar and Surface Capabilities
AES	Advanced Exploration Systems
AER	Ammonia Emergency Response
ASCAN	Astronaut Candidate
BAA	Broad Area Announcement
BEAM	Bigelow Expandable Activity Module
BPS	Biological and Physical Sciences
BP	Boilerplate
CAL	Cold Atom Lab
CASIS	Center for the Advancement of Science in Space
CCAFS	Cape Canaveral Air Force Station
CCP	Commercial Crew Program
CCiCap	Commercial Crew Integrated Capability
CCtCap	Commercial Crew transportation Capability
CDR	Critical Design Review
CFT	Crewed Flight Test
CM	Crew Module
CRS	Commercial Resupply Services
CR	Certification Review
DAEP	Deep Space Network Aperture Enhancement Project
dCDR	Delta Critical Design Review
DDT&E	Design Development Test and Evaluation
DCR	Design Certification Review
DoD	Department of Defense
DOE	Department of Energy
DSN	Deep Space Network
DSS	Deep Space Station
ECLSS	Environmental Control and Life Support System
EGS	Exploration Ground Systems
EM	Exploration Mission
EMUs	Extravehicular Mobility Units
ER	Engineering Release
ERT	Exploration Research and Technology
ESA	European Space Agency
ESD	Exploration Systems Development
ESM	European Service Module
ETA	Engineering Test Article
EUS	Exploration Upper Stage
EVA	Extra-vehicular Activity
FCPF	Fluid Component Processing Facility
FTE	Full Time Equivalent
FOR	Flight Operations Review
FTRR	Flight Test Readiness Review
GFAST	Ground and Flight Application Software
GOES	Geostationary Operational Environmental Satellite
GRC	Glenn Research Center
GSE	Ground Support Equipment
HEO	Human Exploration and Operations Mission Directorate
HERA	Human Exploration Research Analog

Human Exploration and Operations

Acronym List (continued)

- HRP Human Research Program
- HTV H-II Transfer Vehicle
- ICON Ionospheric Connection Explorer
- ICPS Interim Cryogenic Propulsion Stage
- ICU Integrated Communications Unit
- IDIQ indefinite-delivery, indefinite-quantity
- InSight Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
- IDA International Docking Adapter
- ISRU In-Situ Resource Utilization
- ISS International Space Station
- JPSS Joint Polar Satellite System
- JSC Johnson Space Center
- KSC Kennedy Space Center
- LAS Launch Abort System
- LCRD Laser Communication Relay Demonstration
- LEO low Earth orbit
- LH_2 Liquid Hydrogen
- LOX Liquid Oxygen
- LVSA Launch Vehicle Stage Adapter
- LOP-G Lunar Orbital Platform-Gateway (LOP-G)
- MAF Michoud Assembly Facility
- MCC Mission Control Center
- MISSE Materials for ISS Experiment
- MPPF Multi-Payload Processing Facility
- MSFC Marshall Space Flight Center
- MUSES Multi-User System for Earth Sensing
- MUSS Multi User Systems and Support
- NASA National Aeronautics and Space
- NextSTEP Next Space Technologies for Exploration Partnerships
- NET No earlier than
- NDS NASA Docking System
- NICER Neutron star Interior Composition ExploreR
- NIH National Institutes of Health
- NL National Lab
- NSF National Science Foundation
- OA Orbital ATK
- OFT Orbital Flight Test
- OGS Optical Ground Stations
- ORR Operational Readiness Review
- PBR President's Budget Request
- PCM Post Certification Mission
- PLCU Payload Converter Unit
- PPB Power Propulsion Bus
- PPE Power and Propulsion Element
- REALM RFID-Enabled Autonomous Logistics Management
- RED Reentry Device Data Collection
- REMIS Research, Engineering, Mission and Integration Services
- RFI Request For Information

Human Exploration and Operations

Acronym List (continued)

- RFID Radio Frequency Identification
- RISE Revolutionize ISS for Science and Exploration
- RNA Ribonucleic Acid
- RR Readiness Review
- Saffire Spacecraft Fire Experiment
- SAGE III Stratospheric Aerosol and Gas Experiment III
- SCA Sample Cartridge Assembly
- SEP Solar Electric Propulsion
- SCaN Space Communication and Navigation
- SGSS Space Network Ground Segment Sustainment
- SLS Space Launch System
- SM Service Module
- SMD Science Mission Directorate
- SpaceX Space Explorations Technologies Corporation
- SPP Solar Probe Plus
- SSC Stennis Space Center
- SRB Solid Rocket Booster
- STMD Space Technology Mission Directorate
- STA Structural Test Article
- S/W Software
- VAFB Vandenberg Air Force Base
- VAB Vehicle Assembly Building
- VAC Vertical Assembly Center
- V&V Validation & Verification
- TESS Transiting Exoplanet Survey Satellite
- TDRS Tracking and Data Relay Satellite
- TLI Trans-Lunar Injection
- TREAT To Research, Evaluate, Assess, and Treat" Astronauts Act
- URT Underway Recovery Test
- USDA U.S. Department of Agriculture
- USOS U.S. Orbital Segment